

ACTA UNIVERSITATIS UPSALIENSIS

Studia Oeconomica Upsaliensia 12

Christos Papahristodoulou

**Inventions, Innovations and
Economic Growth in Sweden:
An Appraisal of
the Schumpeterian Theory**



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Abstract

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This study investigates the determinants of inventions and the relationship between innovations and Swedish economic growth by utilizing a Schumpeterian approach.

Schumpeter's theory emphasized the analysis of dynamic processes rather than equilibrium situations. In real market economies the assumption of equilibrium is never entirely fulfilled. Non steady-state rates of economic growth frequently appear due to some disequilibrating factors such as innovations. The appearance of innovations which are unevenly distributed over time and across firms and industries, cause economic growth through cyclical fluctuation. The long-run adjustment process which is set into motion, allows for various degrees of competitiveness of market structures, which in turn foster or retard the rate of innovation. In Schumpeter's view monopolistic markets were most likely to promote innovations.

The approach chosen in this study is partial and empirical. Thus, instead of attempting to integrate the determinants and the effects of innovations in an evolutionary model, these two were separated and investigated partially. This procedure can be justified in Sweden where the growth rates of the economy have been relatively stable.

Based mainly on patent statistics and major innovations to approximate innovations and covering a long period, modern causality tests show that innovations tend to have caused economic growth in Sweden. Regarding the determinants of inventions, independent inventors seem to be quite significant, while neither large firms nor monopolistic market structures seem to be more inventive than smaller firms or less concentrated markets.

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Uppsala, April 1986

Christos Papahristodoulou

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Introduction

“When I was a precocious student, I didn’t think much of Joseph Schumpeter’s futurology. But, like Mark Twain, who said that when he was fourteen he thought his father was awfully dumb, but by the time of reaching twenty-one he was surprised at how much the old boy has smartened up, when I reread Schumpeter’s 1942 *Capitalism, Socialism and Democracy*, I find new meanings in it.”

P. A: Samuelson (1981)

The stagflation in the 1970s and early 1980s actualized once again the issue of economic growth. As a consequence, a growing number of economists returned to the investigation of economic growth and structural change.

The importance of technical change for the long-term growth of productivity has always been recognized. Previously, technical change was considered a continuous and steady-state process. The rates of growth during the 1950s and 1960s did justify that assumption. However, the poor rates of growth which characterized many economies during the 1970s and 1980s negated these simplified assumptions regarding technical change.

One theory which attempts to explain both competition and economic growth and decline in terms of innovation is Schumpeter’s¹ (1934, 1939 and 1943). Schumpeter considered the upward trend of national income, consumption, investment and employment as being caused by innovation. Similarly, the downward movement is identified with the completion of a full diffusion process across firms and countries and a simultaneous decline in the number of innovations being introduced. He separated discontinuous from continuous changes and departed from the framework of perfect competition and general equilibrium. He considered the development of capitalism as an eternal movement towards higher or better equilibrium points which might or might not be attained. A considerable part of his work was devoted to determine and analyze the factors underlying innovations.

¹ Obviously, there are numerous economists – regardless of the school or “ism” – who do not deny the significance of innovations. But since innovations are not accounted for in their models, equations, or predictions, they are often neglected.

Schumpeter's theory, however, has often been neglected. There are primarily three reasons which explain why economists have tended to disregard his theory.

First, his main work "Business Cycles", appeared just prior to the Second World War and three years after Keynes' "General Theory". Schumpeter's explanation of the business cycle was not appropriate during a period of high depression with mass unemployment. The argument that business cycles are unavoidable because they mirror the structural changes in an economy, was then considered a pessimistic and irrelevant statement. The Keynesian stabilization economic policy was more appropriate and quite optimistic. As a consequence, Keynes' view prevailed.

Second, while macroeconomic theory was being built on Keynes' "General Theory", microeconomic theory was being built on the neoclassical theory, as presented by Hicks in his "Capital and Value", concentrated mainly on perfectly competitive markets. Schumpeter, on the other hand, advocated the departure from perfect competition towards more imperfect market structures in order to stimulate innovations. This was unwelcomed advice to neoclassicists who implicitly or explicitly assume the superiority of perfect competition.

Third, among the new class of economists to whom mathematical precision is a major scientific criteria, Schumpeter's theory did not gain much respect since the richness of his philosophy can not be formalized in a satisfactory manner. Some part of that theory, however, have been formalized.¹

Many of his ideas have been corroborated by empirical research. Rostow (1978), Mensch (1979), Freeman-Clark-Soete (1982), van Duijn (1983), Evenson (1984), et. al. have shown that crises are correlated with the absence or decline of innovations, and that an upward trend of innovation tend to be correlated with economic growth. In the US, for example, the steep fall in patent applications (primarily) and patents issued (secondly) coincided with the great depression in the early 1930s. Similarly, there was a levelling off of the number of patents which started just before the crisis of the 1970s and continued through the end of that decade. Among the OECD countries, it is only Japan that has experienced a continuous upward trend in patenting.

Sweden's two major crises during the course of this century are also reflected in its patent statistics. The crisis of 1930–1932 might, to some extent, be explained by the sharp decline in patent applications and patents

¹ See for instance, Arrow (1962), Scherer (1967), Demsetz (1969), Nordhaus (1969), Kamien-Schwartz (1976), Englund (1979), Nelson-Winter (1982).

issued which began some years earlier. The continuous increase which subsequently took place might have ameliorated the severity of crisis. The unfavorable development of the 1970s, also seems to be closely related to patent trends. Patent applications reached a local peak in 1967 and a low point in 1981. During that period the decline in the number of patent applications was almost 1400 patents. Patents issued also reached a global peak in 1970 and thereafter declined sharply until 1981.

The use of a Schumpeterian theory of innovations to explain Swedish economic growth does not of course imply that all other theories are considered invalid. It is instead an attempt to stress an important factor which is usually neglected by many model-making economists.

The role of other commonly mentioned growth factors might be better understood through the Schumpeterian theory of innovations. For instance, natural resources such as forestry, iron-ore and waterfalls would probably have remained untapped much longer if the processes for sulfate pulping and cellulose, for steel making, in addition to extracting machines, electric motors and the transfer of high power voltages had not been invented and innovated in this country. Similarly, Swedish economic policy of the 1930s–1960s has probably been successful for a variety of reasons, in addition to the fact they were Keynesian. During these decades, Sweden had an extremely good technological position based mainly on Swedish inventions from the last decades of the 19th century and the first decades of this century. If the peak of the life cycles of these Swedish innovations is estimated to have been reached during the 1960s, it is not surprising that the Keynesian policy of the 1970s has proved to be ineffective.

All studies of Swedish economic growth acknowledge the importance of technological inventions and their implementation. However, it was Dahmén (1950) in his study of the period 1919–1939 who first applied the “creative-destructive” theory of Schumpeter to the Swedish economy. His results support that innovations in Sweden have caused both positive effects (such as the creation and development of new products, processes, markets and industries) and negative ones (such as the decline and death of old and traditional products, processes, markets and industries). Dahmén (1980) argued that this creative-destructive mechanism ceased or was not allowed to work during the end of the 1960s and the 1970s. New products, processes, companies and sectors were lacking, or at least they were not created at the same rate as previously. Consequently, the destructive part of this mechanism could not operate either. Old and traditional sectors and products had to be protected at any price, a policy which proved detrimental.

Instead of retesting and renewing the “creative-destructive” theory in Sweden, a slightly different Schumpeterian approach will be tested in this study. The principal questions to be analyzed are: How does the Schum-

peterian theory of innovations fit in Sweden? Are Sweden's economic growth and business cycles determined and generated by the rate of innovations? Does the causal mechanism run from innovations to investment and output as Schumpeter argued? What is the role of individuals and imperfect market structures to promote innovations? Can one explain the crisis of the 1970s as an accumulation of structural imbalances and particularly as an innovation crisis?

As was mentioned earlier, the real problem which any Schumpeterian economist faces today is how to formalize and integrate the tremendous complexity of this issue and the richness of Schumpeter's philosophy regarding the role of innovations in economic growth. This is undoubtedly the reason why almost all the Schumpeterian models today are partial and empirical. For instance, during the last two decades, there have been some attempts to test the causal direction between innovations and investment. Similarly, a large amount of empirical studies has been undertaken in order to test the Schumpeterian view that large and monopolistic market structures foster innovations to a greater extent than pure competition.

This study will also be partial and empirical. Moreover, since it is limited in several respects, the study does not provide clear-cut answers to the questions posed above. It neglects all other factors except innovations, and concentrates on Swedish innovations alone. Such a limitation would obviously be easier to excuse in a study of the United States today, or of Sweden a few decades ago. Sweden today is a small open economy, and ideally should not be viewed in isolation from other industrialized countries.

Data shortages also, make a detailed investigation of Swedish economic growth since industrialization almost impossible. Thus, while an almost 90 year period will be covered in order to examine the existence of causality between innovations and economic growth in Sweden, only the period of the 1970s will be investigated in detail. The focus will be on the factors which might have influenced the occurrence and the decline of innovations.

In the first chapter the problem of economic growth and business cycles will be examined from the Schumpeterian point of view. The central question will then be, how innovations cause economic growth through business cycles.

In the second chapter we will examine and evaluate some of the most commonly applied measures of innovations, namely Research and Development (R and D) and patents.

Then, based on patent statistics and major innovations, the Schumpeterian causal mechanism presented in the first chapter will be tested in the third chapter.

The role of individuals together with the relationships between firm size,

market structures and innovations will be the subject of the fourth chapter.

Finally, these empirical results in addition to some suggestions for further research will be summarized in the concluding chapter.

A schematic representation of the contents and the relationship among chapters is shown on the next page.

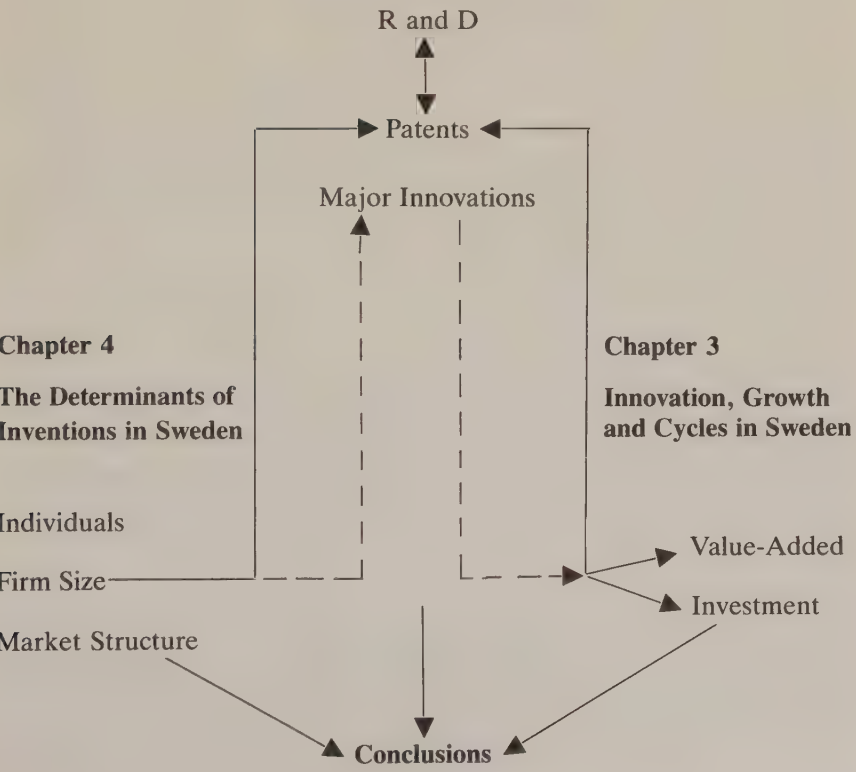
Organization of the Study

Chapter 1

Innovation, Economic Growth and Business Cycles

Chapter 2

The Measurement of Innovation



Chapter 1

Innovation, Economic Growth and Business Cycles

1.1 Introduction

During the 1950s and 1960s economies were flourishing without serious interruptions or crises. Thus, there was no reason to seriously question the dominance of Keynesian stabilization policy or the neoclassical growth theory.

The troublesome decade of the 1970s brought about many changes. Keynesian economic policies, for instance, proved rather weak as an instrument for economic stabilization (Pasinetti, 1981). In addition, stylized facts regarding economic growth in almost all industrial countries provided little support to one of the major implicit assumptions of neoclassical growth theory, e. g. that technical progress, just like population growth, could be expressed as a steady-state process. Consequently, many economists, Bronfenbrenner (1969), van Duijn (1977, 1983), Dupriez (1978), Mensch (1979), Mandel (1980), Graham-Senge (1980), Freeman-Clark-Soete (1982) et. al.,¹ began to think in terms of business cycles and became more receptive to the idea that the rates of growth of an economy should not be expected to be constant over time. This led to a revaluation of the phenomenon of growth.

Economists, however, have not explicitly defined the type of cycle they seek to explain. Those who attempt to do so usually assume some a priori conditions contrary to economic realities or at least contrary to what other researchers have regarded as facts.

Mainstream economists argue that the occurrence of short period cycles is more probable than that of long waves. Keynes (1936), for instance, without a prior investigation of the facts, assumed cycles whose typical length lasted from three to five years.² He considered this period to be long enough for the surplus of stocks and durable capital goods to be reduced considerably, so that the return on investment would improve and therefore result in recovery. This three to five year cycle is conventionally referred to as the Kitchin (1923) or inventory cycle.

¹ A similar interest in the subject of business cycles also appeared just after the great depression (1929). Among the most reputed economists who investigated similar problems then were Kuznets (1930), Hansen (1932), Burns (1934), Kondratieff (1935), Haberler (1937), Schumpeter (1939) and Tinbergen (1939).

² Keynes, J. M., *The General Theory of Employment, Interest and Money* p. 317.

There are also two other types of cycles generally considered: the Juglar or investment cycle with a period of seven to eleven years – which was also studied by Hansen (1941) – and the Kuznets (1930) or building cycle with a period of fifteen to twenty-five years in duration. It should be mentioned that neither the investment cycle recognized by Hansen, nor the building cycle supported by Kuznets are regular in shape.

Finally, the theory behind long waves stems from Kondratieff's original work (1935). Kondratieff collected a large number of time series data in order to explain the relationship between these series and long waves. He placed large investments such as railways, canals etc., at the center of his theoretical explanation of the regularity of long waves. These large investments had, in theory, durability and as they required the binding of important financial funds, shorter cycles disappeared. Because the amount of loanable funds is limited, the interest rate would increase and as a consequence investment would decline resulting eventually in a new wave. However, Kondratieff himself failed to show a clear-cut causal relationship between the time series he collected and long waves.

Researchers in the area of growth, irrespective of their beliefs concerning business cycles or long waves, have also been interested in the causal factors of growth and business cycles. This entails an explanation of the forces which drive the system upwards, why these forces gradually lose their strength after a certain point in time and why they are replaced by forces operating in the opposite direction.

Numerous factors have been suggested as relevant to the determination of business cycles or long waves. These include: psychological factors, weather conditions, wars, discoveries of gold, monetary factors, the construction of industrial equipment, over-production, under-production, disequilibrium situations on markets of raw materials and foodstuff, the "progressive" character of the present age and innovations. Justifying the degree to which these factors might have contributed to the explanation of cycles is obviously a difficult task, if at all possible. In addition, there is the complication that some of these determinants are influenced by others. Since feedback effects are possible in both waves and cycles, it is very difficult to analyze the true causality among these factors and between these factors and long waves and business cycles.

W. C. Mithcell (1927), for instance, argued that there are many forces at work to explain business cycles or long waves. According to him, the first task of inquiry is to find out more about the facts, then to analyze them and finally to employ the existing theories to interpret these facts. Instead of employing statistical criteria for identifying cycles and waves based on what the order and the sequence of the movements are, the researcher should be prepared to analyze numerous statistical series covering a wide range of activities.

1.2 The Role of Innovations in Economic Growth

While the determinants of cycles and/or waves is an open subject, many economists agree that innovation (or technical progress) is one of the most significant factors underlying economic growth. This is not to deny the variation in results of the plethora of empirical studies which have appeared since the late 1950s. Solow, for instance, estimated that almost 30% of growth in US output per worker during the period 1909–49 was due to the effect of technical progress (identified by the residual factor). At the other extreme, Jorgenson and Griliches estimated that almost all observed economic growth in the US between 1945 and 1965 can be due to the growth of conventional inputs, such as capital and labour (see Kendrick, 1973).

Apart from the fact that technical progress appears in various forms, such as neutral, non-neutral and embodied or disembodied in capital or labour, the variation in these results can also be explained by the fact that technical progress is hardly a steady-state process. It is rather a discontinuous, non-constant or even a random process.

When innovation or technical progress is placed at the center of an economic system, economic growth does not exclude the appearance of business cycles. Both cycles and growth could be the results of unevenly distributed innovations.

The upward trend of national income, consumption, investment and employment can be identified with the introduction of innovation. Similarly, the downward trend of these significant variables can also be identified with a complete diffusion process across firms and countries and a simultaneous decline in the number of innovations being introduced, probably due to the lack of inventions previously invented and to unfavourable demand conditions.

Regarding the normality of cycles, one should not expect a single wavelike movement, because there are variations in the gestation and absorption of the effects of innovations by the economic system. Clustering of innovations can also accentuate both the rates of growth and the length of the cycle.

Before we proceed with a discussion concerning innovation, economic growth and business cycles, we must first clearly define the concepts which are related to innovations.

1.3 Some Useful Definitions

Although there is not complete agreement among scientists regarding these concepts,¹ the following definitions are to a large extent accepted by most

¹ Schmookler (1966) in his *Invention and Economic Growth* (p. 3), states characteristically: "Technical change is the 'terra incognita' of modern economics". . . . "we do not even have an agreed upon set of terms".

researchers in the field.

Technology is the existing stock of knowledge, while the rate of technological progress is the degree of increment of that stock. It is considered to increase.

Technical progress is the effect of technological progress. It occurs in the following cases:

- (i) when the same amount of output can be produced by smaller amounts of all or one input, or when the same amount of inputs produce more output.
- (ii) when existing products are improving in quality.
- (iii) when new products are produced.

Invention can also be defined in the same way. Thus, invention is the creation of new technological knowledge, i. e. the creation of things previously non-existent, such as dynamite, the steam turbine, ball-bearings, transistor etc., and the discovery of things which have always existed such as iron-ore, uranium, gold, penicillin etc. Both product and process inventions are, from the practical point of view, useless intellectual constructions if they are not put into actual productive operation.

Innovation, on the other hand, can denote, for instance, the embodiment of these inventions into actual productive processes. However, although an innovation must possess some degree of novelty, not all inventions become innovations. Inventions should be identified with innovations if they are expected to bring about economic yields. Another important point which is worth stressing is that the concept of innovation should not include only technological innovations but innovations in organization and marketing as well.

According to Schumpeter (1939), who introduced the concept of innovation to economic theory, innovation should be defined broadly. His classical definition is:

“We include the introduction of new commodities which may even serve as the standard case. Technological change in the production of commodities already in use, the opening up of new markets or new sources of supply, Taylorization of work, improved handling of material, the setting up of new business organizations such as department stores – in short, any ‘doing things differently’ in the realm of economic life – all these are instances of what we shall refer to by the term innovation.”¹

If, in general, the mother of innovation is invention, it is not certain that the mother of invention should be found in scientific research. Scientific research can also be shaped by technological innovation (Rosenberg, 1981).

¹ Schumpeter, J. A., *Business Cycles* (1939) p. 84.

Scientific research, however, can be categorized into pure or basic research (which is undertaken without any specific commercial objectives) and applied research (which deals with immediate commercial application). A more detailed classification of applied research will also consider the stages of development and design in between invention and innovation.

Finally, comes the stage of diffusion which refers to the spread of an innovation after its introduction or its adaption by the first market or the first user. Sometimes, “diffusion” is used interchangeably with the term “transfer”.

This seven-stage mechanism – pure and basic research, applied research, invention, development, design, innovation, and diffusion – although logical in its sequence, can be considered only a very rough approximation of reality for the following reasons:

First, there are some cases where inventions do not occur in the research stage of the R and D process. This occurs i. e. in the so called “learning by doing” process, or what Lundberg (1961) called the “Horndal effect”. Similarly, innovations are not always generated by inventions. Innovations, or more precisely the diffusion path of innovations, might generate the introduction of new innovations.

Second, difficult questions may arise regarding how one is to determine if inventions are potentially commercial. Kuznets (1962) argues that “since many inventions never reach the development stage, the estimate of their gross economic contribution is a forecast and their net contribution is a double forecast”.¹

Third, neither the cost of the first stages, nor the appropriate time lag between different stages can ever be estimated with great success. These estimations will be rough approximations of the reality. This difficulty is due to the fact that: (a) it is extremely difficult to include all the relevant factors in the cost of invention since no one knows what these factors are; (b) no one knows exactly the introduction and the end period of the different stages.

1.4 The Schumpeterian Theory of Innovations

Despite the fact that almost all theorists have mentioned the role of innovations, it was Schumpeter (1927, 1935, 1939, 1943) who, more than anyone else, placed the main emphasis on innovation as the explanation of business cycles and economic growth.

¹ Kuznets, S., *Inventive Activity: Problems of Definition and Measurement*, (in R. R. Nelson: *The Rate and Direction of Inventive Activity*), NBER, Princeton Univ. Press (1962), p. 28.

Schumpeter could be called a “supply-side” economist because he emphasized the role of autonomous investment and did not give much credit to the demand-induced accelerator investment or multiple principles as factors significant to economic growth. Contrary to traditional “macrodynamic models”, he argued that the true causes of business cycles arise from sectional disturbances and that “cycles are the form that structural changes take”.¹

Although Schumpeter belongs to the “supply-side” school, there are some differences regarding both the starting points of his analysis and the true exogenous factors of the economic system. For instance, in contradiction to many economists, Schumpeter separates discontinuous from continuous changes and departs from the static Pareto optimal allocation of resources which is identified with perfect competition and general equilibrium. He views the development of capitalism as an eternal movement towards higher or better equilibrium points which might or might not be attained. He is nearer to Wicksell than to Keynes as far as the determinants of investment are concerned. It is well known that, although both Wicksell and Keynes have mentioned the large role that expectations have in determining investment, it was Wicksell who more explicitly than Keynes stressed the role of dynamic changes which are associated with inventions and technological improvements in order to influence the natural rate of interest. On the other hand, neither Keynes nor Keynesians have investigated the role of innovations in generating a revival of “animal spirits” and raising the level of expectations for further profits (Freeman-Clarke-Soete, 1982).

Schumpeter’s analysis identified five types of innovations: The introduction of a new commodity, a new method of production, the opening of a new market, the finding of new sources of supplying raw materials, and the new organization of an industry.

As a starting point for his analysis, Schumpeter assumed a state of “general equilibrium”, without profits and interests. Production and consumption are conceived of as being synchronized. The existence of occasional profits which originate from innovations cause disturbances in this state of “general equilibrium”. Therefore, his entire framework is based on an equilibrium – disequilibrium process. These equilibrium situations are connected with various phases of the business cycles.

It should be mentioned that Schumpeter did not count the cycles from peak to peak or trough to trough, because by counting in this way, the fundamental distinction between recovery and prosperity is lost. According to him, recovery is the last and not the first phase of the cycle. Furthermore,

¹ Schumpeter, J. A., (1954), *History of Economic Analysis*, p. 1168.

periods of recession and recovery should be considered as efforts to converge towards equilibrium and when the periods of prosperity and depression are achieved, there are forces operating which drive the system away from its equilibrium. Since the cyclical behaviour is permanent and repetitive, these equilibrium and disequilibrium situations follow each other and should be considered as quasi-equilibrium or quasi-disequilibrium.

Let us now see how the Schumpeterian mechanism works.

We consider for the moment rather favourable socioeconomic conditions, so that innovations are being fostered. To start with, let us also assume that our economy is experiencing a period of depression. Favourable socioeconomic conditions need not be inconsistent with periods of depression. On the contrary, during a long depression generous incentives are usually provided to contribute to economic recovery.

After the introduction of innovations has taken place, opportunities for profits are created or stimulated. That is, provided that innovations are exploited, new investment activities will generate recovery. Financial credit and shifting of factors of production from existing firms and products will in turn facilitate the upward process. In the beginning of that process, costs and prices might rise as a result of the new demand which is created. The revenues from the new products, however, are higher than the rising costs. Higher revenues combined with a steadily increasing optimism which exists in the economy cause a significant expansion of investment. Since the economy is integrated, the revival which started initially in some sectors will be spread over to all sectors.

The transition from recovery to prosperity, however, brings about unfavourable conditions which terminate prosperity and lead to recession. The cumulative expansion of investment causes a decline in prices and an increase in the interest rate. The increase in the interest rate might not be considered as a significantly impeding factor during the first years of recession. There will be some entrepreneurs who continue to undertake investment activities as long as existing innovations are viewed as profitable. The decline in prices which stems from the fact that more and more firms start to produce new products, or use new production processes, is more serious. It is possible that new firms which base their operation on innovations might not be damaged, if they are protected by patent laws, since they can produce more cheaply and can introduce new products. But the old firms will suffer serious losses if they cannot produce, or are prohibited from producing these products or from using such cost-saving processes. This is the general idea of the creative-destructive mechanism. If, on the other hand, imitation is allowed so that innovations are considered to be public goods and all firms have access to them, the rate of profit will soon be completely eroded. The opportunities for higher profits disappear and plans for investment become

more difficult to carry out. If, at the same time, innovators must repay their loans to banks or have difficulties in obtaining more credit due to the pessimism which exists in the market, a recession period will begin. Without new innovations, the system is destined to achieve a new but temporary equilibrium at recession levels.

But why do favourable and unfavourable conditions seem to appear in the downward and the upward periods respectively? Since Schumpeter set innovations at the center of his theory, he attempted to explain the fluctuations of innovations in terms of economic incentives.

First of all, Schumpeter has provided two independent but rather complementary hypotheses concerning the forces behind innovation. The young Schumpeter, (1912), Schumpeter I, stressed the role of individuals, while the older Schumpeter (1939, 1943), Schumpeter II, concentrated on the role of large firms and monopolistic market structures. These two hypotheses led some of his critics to consider Schumpeter's theory as rather weak and conflicting. Such criticisms are, however, exaggerated for the following simple reason. The development of capitalism (Schumpeter's terminology) has been characterized by various stages. The first years of industrialization could therefore be identified with the existence of great inventors and entrepreneurs and subsequently with the establishment of firms and industrial sectors. Later, the role of individuals will decline and large and monopolistic firms are expected to take over inventive activities.

According to Schumpeter, capitalism in its early stage was allowed to work without regulations, prohibitions and any other institutional restrictions. The opportunities to make considerable profits were extremely great. The capitalistic society rose together with the development of a new class of men: The entrepreneurs. Similarly, in the years of depression the "animal spirit" is inspired. The appearance of one or more pioneers is very important as it removes the obstacles for their followers. No follower will make the same profits as the leaders; to make at least a share of that is considered sufficient. This pioneering behaviour might be facilitated by government, however, during downward periods. Higher incentives in terms of loans, taxes, regulation etc. provide a better climate for entrepreneurs and innovators.

During the recent stages of capitalism and especially during the recovery and prosperity periods, the reverse conditions dominate. A hostile social and political environment is a main characteristic of these periods. Politicians, encouraged by various social groups, start to adopt anti-capitalist policies, such as equalization in income distribution mainly through high taxation, a higher degree of market perfectionism through more strict regulation against monopolies, greater intervention in the market economy and generally more socialism. All these policies cause a weakening of

incentives which in turn result in a decline of innovations and of private investment.

Schumpeter's preference for monopolistic market structures does not reflect an extreme or reactionary view. According to him, the superiority of perfect competition to allocate existing resources efficiently (static efficiency) is self evident. However, if one deals with capital formation, technology, innovations etc. (dynamic efficiency) perfect competition might prove to be a rather inferior market structure to promote these goals. Thus, in a Schumpeterian sense (Schumpeter II), the upward and downward periods of capitalism could also be identified with different market structures. For instance, the transition from prosperity to recession will be consistent with the transition from rather perfect competition to imperfect competition, where firms start to rationalize their production, to diversify their products and become more integrated in order to retain their market shares and profits. This "destructive" process ends when there is no room for additional restructuring; that is, when the degree of imperfection reaches its optimum point. The bottom of the depression is to be identified with market structures in which monopolistic and oligopolistic elements prevail. However, these monopolistic and oligopolistic market structures will – at least temporarily – approximately satisfy the requirements of perfect contestability¹ because these firms will operate efficiently, earn very low economic profit and opportunities for entry by potential entrants will be rather weak. Thereafter, along with the arguments stated above, the "creative" process is set into motion, new inventions appear, new profit opportunities emerge, new firms are established for commercial exploitation and the recovery and prosperity years are identified with more competitive market structures.

The Schumpeterian theory presented so far was also supported, to some extent, by De Wolff, Kuznets and recently by Mensch. The main characteristics of this "supply-side school", that innovations cause growth through cycles and waves as in an "echo-wave" model, can be summarized in Table 1.1 (next page).

Thus, setting innovations as the main exogenous² determinant of the system, it is understandable why other commonly applied tools such as demand, interest rate and fiscal or monetary policy are relegated to a secondary place.

¹ See Baumol, W. J., Panzar, J. C., Willig, R. D., *Contestable Markets and the Theory of Industry Structure* (1982).

² In fact, not completely exogenous, since innovations are affected by "social and political environment".

Table 1.1 Innovations and Cycles

Characteristics	Depression	Recovery	Prosperity	Recession
1 Socioeconomic climate		Rather favourable, capitalism promoted		Unfavourable, anti-capitalist
2 Market structure	High concentration Many bankruptcies Establishment of very few new firms	Lower concentration New Markets Free entry	High competition High entry High imitation	Lower competition Increase in diversification mergers Bankruptcies
3 Propensity to innovate	Very high, especially in old sectors	High only for major innovations	Rather low	Low in the beginning higher at the end
4 Investment	Excess capacity	Increasing	Very strong increase of capital formation	Rationalization, declining
5 National Product	No growth	Increasing	Very high growth	Declining growth
6 Employment	Very low	Increasing	Full	Declining

Schumpeter's "supply-push" theory of innovations has indeed a special meaning. It contradicts the "actual demand-pull" theory but could be identified with the "latent demand-pull" theory of innovations. Schumpeter, as is known, differentiated actual demand from latent demand or more correctly generated demand. He recognized, of course, that there are some actual needs which should be satisfied through innovation, but these needs very rarely cause the kind of innovation which will satisfy them. Human needs can be satisfied in many different ways and not only through innovations. Thus, the successful entrepreneur who looks forward, thinks in terms of latent demand or how to satisfy future needs. Schumpeter has an answer to the standard question posed by the "demand-pull" economists; why a particular innovation, for instance the motorcar, did not appear much earlier. He says:

"The sense in which it may be true that motorcars emerged when conditions called for them is not relevant to an economic inquiry. For any 'need' for them that may have existed was certainly subconscious and not an element in the then existing system of economic values. The 'need' as far as economically relevant, was created by the industry, and people could obviously have gone on without any motorcars."¹

A similar argument could have been used for thousands of modern products and services. People, some decades ago, had no idea about Coca Cola, or videos. There was not even a need for them. Nowadays, there are millions of people all over the world who have been taught to drink Coca Cola and be entertained by their videos. The fact that videos appeared recently and long after television sets should be regarded as a subsequent application of a known technique together with some latent demand, and not due to the actual demand for videos. Science cannot resolve all problems and satisfy all actual needs. There has been a tremendous demand for cancer treatment for a long time, but quite recently "some" cancer cures have been developed. Thus, it might take a considerable time lag between demand pressure and the development of an innovation.

For similar reasons, actual interest rates on borrowed money seem to be rather weak determinants of investment activities when these rates are compared with innovations. This reasoning is not intended to imply that entrepreneurs are irrational, but their rationality and "animal spirit" is also influenced by factors other than the interest rate. Entrepreneurs, before they make any investment decisions, might not be satisfied by looking only at the rate of interest.

¹ Schumpeter, J., *Business Cycles* (1939) p. 85.

As long as the market is saturated with “typical” products, where the expected return on investment will be low, activities might not be undertaken even if there is high liquidity and cheap loans available. On the other hand, provided that an invention makes profitable the production of a new product with high demand, investment projects will be undertaken even if the interest rate on loans is high. In this connection, Dahmén (1984)¹ has said:

“The real rate of interest rate (not to be mixed with the deflated nominal rate of interest) clearly is an ‘entrepreneurial’ concept, sometimes connected with ideas of prospective innovations.”

The return to investment or expected profits will thus, to a great extent, be determined by innovations.

Economic policy may also become inefficient if the role of innovations is not properly evaluated. If policy makers have not taken into account the flow or the stock of innovations or have under(over)-estimated their role, economic policies might prove to be ineffective or even incorrect. Suppose, for instance, that policy makers have overestimated the role of innovations. An expansive fiscal and/or credit policy might have been implemented in vain if the innovation(s) in question have proved to be insignificant. On the contrary, a restrictive economic policy might have brought about better results. Similarly, a restrictive monetary and fiscal policy might have been a catastrophe if policy makers have judged as insignificant an innovation(s) which was later proved to be very important.

Schumpeter is not alone in giving little credit to stabilization policy. Pasinetti (1981), the famous Keynesian economist, argued that Keynesian demand-stimulating policies admittedly can help to avoid a collapse of the system during recessions. However, they will not alter the “structural demand” problems which are related to the principal difficulty of the system, i. e. of identifying and promoting new consumer demands. To quote him:

“the economic system will at least enter a period so to speak, of ‘pause’, until new types of products for expansion or new interests in old products are found (which is a learning process that may take quite some time). Only then will expansion be started all over again.”²

Schumpeter’s view of economic policy was rather different. His wish was that economic policy should serve to facilitate conditions so that the crea-

¹ Dahmén, E., *Schumpeterian Dynamics: Some Methodological Notes*, IUI, Stockholm (1984) p. 33.

² Pasinetti, L. L., *Structural Change and Economic Growth*, (1981), p 235.

tive-destructive mechanism was allowed to work freely. This could be facilitated by, for instance, seeing that the patent system functions as intended. If inventive activities are not stimulated by the patent system, this does not imply that the system should be abolished. By so doing, the short run welfare of society might be increased but incentives will also decline with undesirable consequences. On the contrary, strengthening the patent laws by increasing punishment for imitation, and fostering inventive activities through financial and technical support to inventors, might stimulate superior results.

1.5 Critical Views and Empirical Studies

The Schumpeterian theory of innovation has been frequently questioned.

First of all, Schumpeter did not explicitly refer to short cycles or longer ones.¹ He deliberately left this subject open. This is obviously understood because differences in the degree of significance of innovations and their point of introduction, would cause several kinds of cycles differing in duration and in amplitude. Kuznets (1940), for instance, argued that the discontinuity of opportunity is more relevant to the most revolutionary innovations such as steam power, electricity etc., i. e. innovations that bear upon Kondratieff's cycles. On the other hand, one can hardly expect significant fluctuations in the stock of innovative opportunities of the type that are related to the Juglar or the Kitchin cycles.

Kuznets also questioned the connection between the distribution of entrepreneurial abilities and the bunching of innovations. According to Kuznets, cycles in the supply of entrepreneurial abilities are not very likely. As a consequence, the discontinuity in the appearance of innovations might be due to the possible discontinuity in the appearance of inventions and to the variations in the opportunities for major innovations.

The exogeneity of innovations and their association with business cycles has also raised a number of critical points.

For instance, business cycles which are regular in shape and duration cannot be consistent with "exogenous" innovations. This is self evident because, even if we accept the Schumpeterian argument that innovations are more likely to take place during downward periods, such periods are indeed a part of the cycle. Schumpeter himself accepted Juglar's statement

¹ In his *Theory of Economic Development*, however, Schumpeter concentrated more on the Juglar type of business cycles and considered this cycle as an investment cycle being caused by innovation. Also, in his *History of Economic Analysis*, Schumpeter expressed his admiration of Clément Juglar "who was a physician by training, but must be ranked, as to talent and command of scientific method, among the greatest economists of all times" (p. 1123).

that “the only cause of depression is prosperity”. If then prosperity is caused by innovations and innovations occur mainly during depressions, then the exogeneity of innovations is doubtful.

The difficulty of separating the interdependence of the economic elements in the system has also been recognized by Nelson and Winter (1982). They argue that, even if we temporarily accept that monopolistic firms and market structures underlie innovations, as the Schumpeterian one-way mechanism suggests, in an evolutionary world firms and market structures are also shaped by business cycles and economic growth.

In defence of Schumpeter, one could point out that he argued that the existence of cycles, regular in duration, is unlikely because there are variations in the gestation and absorption of the effects of innovations by the economic system. Schumpeter did not deny the effect of economic growth and business cycles on firm size and market structure. What he mainly stressed was the positive effect of monopolistic firms and market structures on innovations. If, business cycles and economic growth weaken the monopolistic elements of market structure, this will be mirrored in the subsequent cycles and growth period. (We return to this point in the fourth chapter).

The exogeneity of innovations has also been questioned from a different perspective. Some of his recent opponents, Schmookler (1966), Forrester (1977), and Graham-Senge (1980), have gone so far as to assume a reverse causality, that is, innovations are caused by growth and cycles. Their main argument was that since many innovations require capital investment in plant and equipment for their production or implementation, innovations would follow investment. Therefore, when a new upswing begins, investors start to exploit new technologies that have gone untapped for decades. Schmookler, however, was primarily interested in inventions and argued that both demand and accumulated knowledge are necessary for invention and that neither alone is sufficient because without demand no problems would exist and without knowledge these problems could not be solved. But despite the fact that both knowledge (supply) and demand factors are necessary, he later neglects the supply side and derives the supply of invention from the demand for it. He states characteristically:

“The essential point is that inventions in this domain can hardly be well understood unless we know why some people want them. The mere fact that they are feasible is not enough.”¹

¹ Schmookler, J., *Invention and Economic Growth* (1966), p. 188.

Schmookler also was thinking in terms of latent or expected demand, "rather than in terms of the definite demand functions postulated for analytical convenience in conventional economics".¹

Van Duijn (1983) has also criticized the "supply-side school" because by concentrating on the simple causality between innovations and long waves it has neglected the role of infrastructural investment and other determinants.

The "demand-side school" has also been criticized by Rosenberg (1974), Scherer (1982) and van Duijn (1983), focusing primarily on two issues. First, the role of demand is of limited explanatory value unless one can define and identify it independently of the evidence that the demand was satisfied. Second, one needs to know how to create demand, which cannot always be derived from existing or latent desires, needs, or demands. Latent demand is rather difficult to define if invention to satisfy it has not already been invented.

Investigating the empirical studies² which have been undertaken during the last two decades, we can conclude that there is a slight evidence in favour of the "supply-side school", i. e. that innovations tend to cause cycles and waves. The only completely opposite result has been found by Schmookler (1966). Based on inventions in 23 industrials sectors and using the coefficient of correlation as a criterion of causality, he found that the strongest r 's emerged when successful patent applications of 1940–42 and 1949–50 were related with 1939 and 1947 investment respectively.

Scherer (1982) retested Schmookler's hypothesis by using a larger sample (433 large U. S. corporations), defined at higher levels of disaggregation for the period 1972–77. His coefficients of correlation are much lower than Schmookler's, but he does not verify any time lag between the emergence of demand pull influences and the time when invention occurs.

Higgins (1971), using data for U. K. patents covering more than a century, supports the "supply-side" theory, since variations in investment in the U. K. appear to follow those in patent activity.

Mensch (1979) has shown that the frequency of basic innovations has appeared in bunches during long-wave depression phases, such as during the 1760s, 1830s and 1840s, 1880s and 1930s. Since he supports the existence of long waves, a new swarm of basic innovations might have appeared in the 1970s whose effects will be expected to appear in the coming decades.

¹ Op. cit. p. 184.

² At this point we are concerned with studies which investigate the causality between innovations and cycles or growth only. The relationship between market structure and innovations deserves a detailed investigation. That will be the subject of the fourth chapter.

Freeman-Clark-Soete (1982), based on 195 major British innovations covering the period 1920–1980, argue that their results “do permit some confirmation of Mensch’s theory of technological stalemate – a decline of basic innovations when the peak of long wave expansion has passed”.¹

Beggs (1984), examining historical data on patenting for twenty selected industries and thirteen census years between 1850 and 1939 and relating them to value-added across industries, rejected the Schmookler results.

Madhavi (1972) has found that innovations are ususally delayed until the time when other factors such as market demand, political pressure, competition and lack of demand for existing products have facilitated the conditions for introduction of these innovations.

Finally, van Duijn (1983), studying 160 major innovations introduced during the 19th and 20th centuries, has shown that any differences in the ocurrence of these innovations are merely chance variations and not a function of supply or demand contidions.

1.6 Conclusions

The Schumpeterian theory of innovations, economic growth and business cycles has been and hopefully will remain a rich source of inspiration in our effort to understand the development of capitalism. This inspiration remains, despite the possible doubts one may have about the one-way causality between innovations and cycles provided by Schumpeter. After all, the best argument to support or reject such a theory should be looked for in empirical results.

The entire Schumpeterian theory of innovation, discussed briefly in this chapter, cannot be tested. Only partial tests, based on its central core, can be performed. The “core” of the Schumpeterian theory can be said to consist of two parts. In the first part, the exogeneity of innovation and its economic impact on growth through business cycles is the main theme. The second part provides two independent, but not necessarily conflicting, sources or determinants of innovations: individuals or entrepreneurs and rather strongly imperfect market structures.

Fortunately, the steady-state economic growth with some weak interruptions which has characterized the Swedish economy (see chapter three), support the choice of this partial testing procedure and facilitate the performance of exogeneity tests.

But before we turn to the empirical investigation of Schumpeter’s theory of innovation, it is necessary to evaluate the two most commonly applied measures; R and D and patents.

¹ Freeman, C., J. Clark, L. Soete, *Unemployment and Technical Innovation* (1982), p. 51.

Chapter 2

The Measurement of Innovation

2.1 Introduction

In all sciences, and especially in social sciences, a generally accepted definition of the problem under investigation and a good proxy measure for the variables used are the necessary conditions for successful empirical research. Since a central problem of this study is to investigate the role of innovations in the growth process in Sweden, the validity of our empirical results will to a large extent depend on the way we measure innovations. Those who consider our proxies as weak and biased will obviously suspect the findings.

Any attempt to operationalize innovations brings about an inevitable and endless debate regarding the best proxy to measure that broadly defined concept. All existing measures, patent applications and patents issued, R and D figures, and major innovations are more or less deficient. Are patent applications or patents issued identical with the introduction date of an innovation? What is the appropriate time lag between inventions and innovations? Are the life cycles of innovations limited to one long wave or business cycle or can they stretch over more than one long wave and business cycle? What is the interaction between a product and a process innovation? Which of these two is more important?

R and D activities are risky, take time, and the private rates of return vary greatly due to externalities (Mansfield et. al. 1977). Similarly, figures on patent applications indicate the willingness to innovate, while patent approvals show the ability to successfully innovate. There is no unanimity regarding the appropriate time lag between inventions and innovations. There are some inventions which become innovations without any significant delay, while the majority of innovations lag behind inventions by some decades (van Duijn, 1983). Finally, the life cycle of an innovation is not an uncomplicated matter. According to Utterback (1979), every innovation consists of two parts, the product innovation and the process innovation, whose life cycles should be separated. The first stages of an innovation are usually identified with a product innovation. Later on, this product innovation leads to process innovation(s). Thus, process innovation(s) are directly affected by new ideas about product innovation. However, one may consider the existence of the reverse mechanism as well, that is a process innovation which makes possible the production of new products.

These questions are unanswered and will remain so for a long time. In this thesis, however, no attempt will be made to investigate all these matters. There will by necessity be some “holy” or “heroic” assumptions, the validity of which is extremely difficult to test; only supporting arguments can be provided.

We begin in section 2 with a general discussion of various measures suggested to approximate innovations. Section 3 investigates in detail the R and D and patents relationship. In section 4 an attempt is made to evaluate the patent statistics in Sweden. Finally, in section 5 we summarize the main findings.

2.2 Input versus Output Measures

Schumpeter’s broad definition of innovation makes its measurement quite difficult. In fact, all measures suggested and commonly used are quite crude. In general, it can be said that, depending on the stage of innovational procedure one is interested in, either input or output figures can be used. Thus, the first stages (basic and applied research) can be better approximated by investigating R and D figures, while the later stages (invention, development, innovation and diffusion) should be measured by residuals, patents and major innovations. Unfortunately, not only are these measures rough approximations, they are, to some degree, deficient and not appropriate for empirical research of this type.

2.2.1 R and D statistics

The internationally accepted R and D definition (applied also by the Swedish Central Bureau of Statistics, SCB) is, all activities which on systematic ground aim to increase the stock of knowledge and use that knowledge to produce new products, systems or methods or to improve the existing ones. Accordingly, since R and D figures are expressed in rather comparable units, their use has often been preferred as the measure of innovations.

These figures, however, suffer from the following weaknesses.

First, R and D expenditures exclude individual and independent inventors but include expenditures for successful and non-successful products and processes. In many cases, inputs are used to develop research which has been invented somewhere else or to buy license rights or to apply for a patent right. Thus, the need for higher disaggregation of the R and D figures becomes apparent.

Second, since R and D expenditures are tax deductible, the figures presented by the companies and the official statistics might be highly overestimated.

Third, even if the R and D expenditures are not overestimated, the only thing they reveal is a worthwhile effort. However, it is not the will that matters, but rather the result or output of this will which is of interest.

In Sweden, R and D figures have been published since 1963 every second year and were, until 1981, based on enterprise statistics. Such statistics cover 70 to 80 percent of the value-added and employment according to the manufacturing statistics. In the survey of 1983, an attempt was made to investigate all the industrial companies with more than 50 employees.

2.2.2 Patents

Patent statistics have often been the preferred measure of inventions and innovations, mainly for three reasons. First, such figures are nearer to the final stages of inventive activities. Second, they show not only the willingness to innovate as R and D figures do, but the ability to innovate as well. Third, reliable historical data exist – though not easily collected. Consequently, patents are to be regarded as a more useful measure in empirical studies of this type.

Despite the fact that many researchers have supported the use of patents and advised others to work with them (see Griliches et. al. (1984)), their validity has always been questioned. This is due to the following weaknesses.

First, it is usually argued that not all inventions are patented because the firm does not want to undertake certain costs: those of possible litigation in defending the patent and those of time which a bureaucratic patent authority implies. Arrow (1962), for instance, argues that patents are not the only way to maintain property rights in an invention; secrecy might be another way. According to Comanor and Scherer (1969) there are four reasons why the propensity to patent inventions of a given quality in the US has been declining: changes in judicial interpretations of the patent and antitrust laws, the character of industrial innovative activity, the proportion of R and D efforts supported through government funds, and the Patent Office's budgetary situation. One may also add the possibility that it is rather difficult to obtain full patent rights and that imitation is a common problem.

Second, in order to obtain a complete picture of the inventive-innovative activities of a small open economy like Sweden, reliance on domestic statistics is not satisfactory. One should have to investigate foreign patent

offices also, if Swedish firms fear more international competition and as a consequence they increasingly seek international protection by patenting abroad instead of patenting at home.

Third, it is also argued that the number of patents reported or registered might be a very crude and/or erroneous approximation of inventive-innovative activities, because of the "sleeping-patent" hypothesis. Swan (1970), and White (1972), for instance, have argued that one obtains a patent right which is not used but is held in order to prohibit anyone else from entering the market.

Fourth, patent statistics as they are published are very poor indicators of inventive-innovative activities because they do not reveal anything about the composition or the quality of patents. Variations in quantity do not necessarily imply direct variations in quality. The economic evaluation of, say, patents during one year is an extremely difficult and time consuming task.

These weaknesses, though evident, might be less problematic in the case of Sweden. In this section, we will attempt to discuss the first three arguments, while the validity of the fourth argument will be discussed later when the R and D-patents relationship is analyzed.

Comanor's and Scherer's views are not very persuasive in Sweden. For instance, in Sweden, a patent has a maximum nineteen-year term, measured from the day of application and the continuation fees have remained unchanged. The proportion of industrial R and D efforts supported through government funds has been stable at about 13 percent. The Swedish Patent and Registration Office (S.P.R.O.) has been one of the most efficient in the world, since the average time period between patent application and patent issuance was, during the previous decade, a little less than 24 months.¹

With regard to the poor reliability of the domestic patent statistics the following comments can be made. First of all, through international agreements such as the Patent Cooperation Treaty (PCT) and European Patent Convention (EPC) the patentee is given a priority right in all member countries if he or she applies for an international patent in any member country and pays all the relevant fees. This priority is obtained automatically from the first day of application. When we take into account that the large internationalization of the Swedish industry started during the past

¹ According to Firestone (1971), the average time period between patent applications and approvals is 2.9 years for Canada and the U. K., 3.1 years for U.S.A., 3.5 years for the Netherlands, 4 years for West Germany and 4.3 years for Japan, while in Sweden it varies between 18 and 24 months (own calculations for many firms during the 1970s). S.P.R.O. in its annual report (1982) estimates that the average processing time has lengthened over the last 3-4 years by 12 to 16 months.

two decades or so, and considering the high efficiency of the S.P.R.O. – which is a member of the PCT and EPC – there is no reason to assume that Swedish firms take out patents abroad and not at home. The assumption that it is more convenient to apply for a patent in Sweden first, is supported also by Generyd (1981).

As far as the “sleeping-patent” hypothesis is concerned, there are reasons for discarding that hypothesis in the case of Sweden. First, patents take time, require financial resources and the full time occupation of researchers, and therefore the opportunity cost is high. Why then would researchers be employed to invent if the patent is to remain “sleeping” for some time? In Sweden one obtains patent rights for a maximum of 19 years (previously it was 17 years) measured from the date of application. Since it takes two years on the average until a patent application is considered, 17 years remain to exploit that right. If that right is not used for some years, one must wonder if the remaining time will provide sufficient “pay back” profit. Second, according to Swedish law, the patentee who has been awarded a patent right and prefers not to use it, is forced to pay higher fees than those who use it. It must be pointed out that the fees paid are highly progressive during the subsequent years. Third, Swedish courts have the right to award patent licences to other interested parties for various reasons such as:

- (i) if the patentee has not used his patent right within three years since he was issued the patent.
- (ii) if the non-use of the patent issued impedes the use of another patent which is dependent on that or if non-used patent is based on a previously awarded patent.
- (iii) if society feels that the use of the patent would benefit the public. (Neuemeyer, 1977).

The “sleeping patent” hypothesis is a specific assumption which was made in order to show that the monopolistic firm does not have high incentives to invent new products, and such an assumption can be true or false. The above arguments indicate that in Sweden it is more reasonable and more unbiased to assume that all patents are used than to assume that some have remained “sleeping”.

Finally, regarding the willingness and ability to patent innovations, two empirical studies show contradictory findings. According to Firestone (1971) patenting was an important factor in R and D activity in large Canadian firms during the 1960s, while Hall-Griliches-Hausman (1984) found that among 642 US firms with high research intensity, 20 percent did not apply for patents in 1976.

In Sweden, two requirements must be fulfilled for a patent application to get issued.¹ First, the invention must be new and differentiated from what is already known. Second, it should be classified as technically feasible.

Both requirements, and especially the second one, are rather difficult to interpret in practice. In general, theoretically scientific inventions, such as mathematical theorems, computer programmes, new methods of operation or treatment of human bodies, new methods of education, administration, organization, book-keeping, management etc. are not patentable. Therefore, we should be aware that by concentrating on patent statistics, some portion – hopefully a small one – of innovations is excluded. Remember that Schumpeter's definition of innovation is very broad and not limited to technological innovations. By concentrating on patented innovations our results will be biased but consistent, if the share of non-patented innovations has not changed over time.

These statistics, as they are published, are not appropriate for economic investigations. For instance, the published patent statistics do not separate Swedes from foreigners. The separation of process from product patents is also lacking. Finally, the classification of patents applied by the S.P.R.O. – which is similar to the International Patent Classification (IPC) – is rather different from the standard industrial classification schemes (SNI or ISIC) which are applied in industrial statistics. Therefore, a considerable amount of time is required in collecting and organizing all the relevant statistics.

2.2.3 Major Innovations

Obviously, not all patented inventions are equal in worth. There might be a few which are “revolutionary”, “radical” or “major” while the majority of them are “insignificant” or “minor”. Accordingly, in empirical studies, one has to take into consideration the economic value of these inventions.

Although such a classification is desirable, there are certain problems which remain with “major” innovations. First, there are no satisfactory objective criteria to use in selecting these major innovations.

It usually takes a certain duration of time until an innovation is characterized as major.² Second, the success of an innovation will depend on its

¹ The S.P.R.O. is one of the few patent offices in the world which consistently and strictly follows the international patent laws and conventions, that is “what is on the books”. (Neumeyer, 1977, p. 19.)

² When Jewkes, Sawers and Stillerman wrote the first edition of their *Sources of Invention* in 1958, they believed “that the electronic digital computer seemed to have so uncertain a commercial future that we decided to exclude it from our case histories then” (Jewkes, Sawers and Stillerman, 1969 p. 11). However, today no one has any doubts about the great importance of the electronic computer.

diffusion path. Should the introduction of a major innovation be identified with the day of its patent application, its patent approval or the date when it begins to yield economic reward?

By definition, when an invention is introduced into the market it becomes an innovation. Similarly, when a major invention comes into the market it becomes a major innovation. It usually takes some years until an innovation can be identified as being a major one. But this does not imply that one should identify some point on its diffusion path as innovation. Innovation must be identified with a point in time. Innovation refers to a specific date and not to a profitable time period.

Another obvious problem remains regarding major innovations. If we attempt to classify major innovation *a priori* (as Schumpeter's entrepreneurs have been doing) and evaluate their economic effect, there is great risk that our classification and evaluation will be incorrect. Thus the difficulties in judging a major innovation in advance force us instead to make that judgement in retrospect. But since only economically successful innovations pass the criterion of importance and are consequently viewed as "major" any investigation of their economic impact becomes trivial. What is of interest to study then, is first, to see to what extent these major innovations are identified with major inventions immediately without time lags, and second, to identify the conditions which might have favored their occurrence.¹

Regarding the major innovations in Sweden, an attempt was made to include those innovations which have fulfilled the following three requirements. They should be: first, Swedish or semi-Swedish – i. e. invented abroad and innovated in Sweden almost simultaneously with their introduction date elsewhere. Second, yield an economic output which is generally accepted as high, such as the foundation of a company of a considerable size (by Swedish standards), and/or an annual turnover of at least 50 million SEK for a period longer than 10 years, or a cumulative turnover of one billion SEK for a shorter period. Third, these innovations must also satisfy some technological conditions which are necessary for an invention to be approved by the S.P.R.O.

¹ Schumpeter, although he distinguished invention from innovation while he was studying the economic effect of innovations, tended to identify the introduction of steam power, electricity and the like as *inventions* rather than as *innovations*. This is probably the weakest point of his entire work. For some other criticisms, see S. Kuznets, "Schumpeter's Business Cycles", *American Economic Review*, June 1940, pp. 257–71.

2.2.4 Residuals

The production function is generally employed by economists to investigate how and to what extent changes in inputs – traditionally capital stocks and labour force – can explain variations in the value of production. The specification which describes the transformation of the inputs into outputs is usually assumed to be either of a Cobb – Douglas, C.E.S. or translog form. In practice, even if the economy is assumed to be competitive and the production homogeneous of degree one, there is always a small part of output left unexplained. This unexplained growth in output is the residual, or what Denison (1964) has called “the measure of our ignorance”.

We all agree that if inputs are being correctly measured and the production function is homogenous of degree one, the residual must be identified with technical progress. The interesting question which then arises is what the determinants of these residuals are. R and D inputs undertaken some years earlier are usually considered one of these explanatory variables, but that is a rather gross estimation. For instance, it is extremely difficult based on simple production functions such as Cobb-Douglas, to evaluate the degree to which the R and D expenditures influence the inputs or simply shift the production function in a neutral way. A classic Schumpeter (1939) assumption is that innovation should be identified with changes in the specification of the production function and not with changes in the quantities of factors. If R and D expenditures influence real capital (capital embodied) and/or labour (labour embodied) they should not appear in the residuals.

The production function approach, that is identifying innovations with residuals and then analyzing that element, will not be discussed in this thesis. This is partially due to the difficulties mentioned above and to the fact that numerous studies employing production functions have already been undertaken (see Panas (1985) for a recent study on production functions). Perfect competition, steady-states, marginalities, and calculus which characterize the production function approaches are anyhow not appropriate tools in a Schumpeterian analysis. The relationship between R and D and productivity growth will, however, be investigated in Appendix A.

2.2.5 Other Measures

Apart from the measures suggested so far, all of which are often used by researchers in this area, other measures include: royalties paid for licenses of patents, trade marks, know-how, fees paid for joint ventures etc.

The internationalization of economies which has taken place over recent years makes the use of these measures desirable, but in practice these

measures are largely ignored. This is in part because the interpretation of the existing data is rather difficult. For instance, royalty fees paid do not differentiate between licenses for patents and trade marks or know-how and joint ventures. Paying royalty fees to purchase a trade mark is not the same as undertaking some costs to participate in a joint venture to develop a product or a process. Nor is it the same as innovating at home. The purchase of a trade mark should not be considered as having the same impact as domestic innovations.

Those product or process trade marks which have been purchased were first innovated elsewhere and have probably reached us with a considerable time lag, or when their life-cycle starts to decline. Similarly, by participating in joint-ventures, the result of this co-operation might not benefit Sweden to the same degree that it would if R and D activities had been undertaken at home. The return from domestic R and D activities might be higher than the return from participation in joint ventures with foreign firms, sectors, or nations. Thus, there might be a weak link between the amount of royalty fees paid and innovations.

All these measurement errors, together with a lack of appropriate statistics, discourage the use of these alternative measures. This is obviously a very serious limitation when we take into account that most of the world's R and D activities are undertaken outside Sweden and are likely to influence its economy.

At this point, it would be worth noting the deterioration in Sweden's "technological balance of payments" which has taken place during the 1970s. In 1971, the revenues from licenses, patents, royalties etc. in the private industrial sector were in balance with the costs (almost 100 million SEK). In 1979, the revenues increased to 150 million SEK and the costs to 220 million. Over the same period, Swedish firms increased their financing of R and D expenditures abroad from 50 to 500 million, while foreign firms have increased theirs from 25 to 100 million.¹

We can therefore conclude that all measures suggested to approximate innovations are, to some extent, deficient and partial.

¹ The costs for licenses etc. in 1983 amounted to 468 million and the revenues to 655 million. This implies a large increase in the technological trade compared to previous investigations. However, these values are not directly comparable with previous ones because they also include transactions between groups and parent companies which are rather high. See SCB, Serie U, 1981:18, 1985:14,

2.3 R and D and Patents

Among the various measures suggested in the previous section to approximate innovations, R and D and patents are often preferred by many researchers. The inclination toward both R and D and patents appears to indicate that both measures provide similar results regarding inventive and innovative activities. But if different measures reveal opposite trends, the problem of choosing the best measure is serious. Thus, additional tests are required to investigate whether patents are superior or inferior to R and D statistics, or if they should be considered as substitutes for each other.

A reasonable approach to the problem mentioned above is to examine and analyze the relationship between these two variables. Prior empirical and theoretical research on the R and D-patents relationship is rather scarce. Mueller (1966) found a positive relationship between R and D figures (expenditures and employment) and patents issued to a number of firms. The highest correlation was obtained when patents issued were lagged by four years – which is similar to the mean time between initial application and patent issuance for that period (1958–1964). Two recent studies by Bound et.al. (1984) and Pakes-Griliches (1984) support Mueller's results. However, these two studies were slightly different compared to Mueller's estimations. Bound et. al., for instance, found that the elasticity of patenting with respect to R and D tends to decrease for the largest firms of the sample. Pakes-Griliches' estimates, on the other hand, show a significantly negative trend term coefficient, which can be attributed to either the declining propensity to patent in U. S. manufacturing or to the decline in the private productivity of research resources.

There are at least two main difficulties with this approach. The first concerns the appropriate functional or “causal” relationship between R and D and patents. There is no unanimity among researchers on the question whether R and D and patents are dominated by a contemporaneous relationship or by leads or lags. The second concerns the existing data on both patents and R and D variables. For instance, patents might be only a fraction of the output of R and D; a large share of patents granted might be of a low quality or become worthless in a short period of time; or the propensity to patent might vary over time and across firms. Similarly, the inadequate statistics on R and D, as they are published, might include errors of measurement.

2.3.1 The R and D – Patents Relationship

It is argued that a simple “input-output” approach is appropriate to describe the relationship between R and D and patents (Mueller 1966).

According to this simplistic approach, patents should be considered as the output of R and D activities. The use of this approach seems to be more relevant now than in the past. In the past, it was possible that many patents were the result of individual effort and of good luck. There was not much serious organized research activity. At the same time, early technological inventions needed rather modest, if any, financial support. Therefore, it is quite logical to assume that in the past inventions were not related to research activities and occurred rather randomly.

Things have changed since then. "Little science" has been replaced by present-day "big science". The possibility of exogeneity of inventions seems to be rather low. Inventions are no longer thought to "fall from heaven". On the contrary, they are generated by the R and D activities undertaken in laboratories of enterprises.¹ Thus, R and D should be considered as the "exogenous" variable and patents the "endogenous" one.

As far as the degree of correlation between R and D and patents is concerned, there is not much dispute. But, regarding the "causality" between these two variables there is a view which is diametrically opposite to that which was expressed in the previous paragraph. Rosenberg (1974, 1981), Vedin (1982) and Stoneman (1983) are the main supporters of exogenous patents. Especially Rosenberg, in his 1981 paper, questions the exogeneity of R and D activities (he uses the term science). The argument is that technological inventions (he uses the terms technology or technological knowledge) have normally preceded scientific research both in the past and in the present. He bases his view on the economic incentives which underlie technological inventions. An invention will become a successful innovation if it satisfies some criteria imposed by the producer and the user. It is not necessary to understand scientifically the phenomena involved in that invention. Later on, one can consider the link between technological knowledge and science. To quote him:

"technology has acquired some bodies of knowledge first and, as a result, provided data which, in turn, became the explicanda of scientists, who attempted to account for or to codify these observations at a deeper level".²

Rosenberg supports his view by referring to many examples from the world of technology during the last century. Finally, Rosenberg proceeds even further and provides some answers to why technological inventions are so important to the direction of scientific research. He stresses the roll of incentives, that is if a new technology is perceived to be economically

¹ In this chapter we are not interested in the optimal size of the enterprise in order to maximize inventive activities. This problem is the subject of the fourth chapter.

² Rosenberg, N., *How exogenous is science?* IVA-PM No. 13, Stockholm (1981) p. 11-12.

successful a large amount of scientific research will be consciously undertaken for many subsequent years in order to provide a series of new developments.

Vedin (1982) also argued that invention often preceeds R and D. His argument, in short, is that an initial idea leads to invention which is patented to prohibit competitors from using it. At the same time, R and D resources are devoted to further exploit and develop that invention which results in subsequent and related inventions. The initial invention then, does not require substantial resources. In fact, it may as well have been purchased.

A third view is suggested by Hall-Griliches-Hausman (1984). According to them "the strongest thing one can say is that R and D and patents appear to be dominated by a contemporaneous relationship, rather than leads or lags".¹ They justify this moderate view not only by combining the theoretical arguments provided above, but also by referring to Pakes-Griliches' (1984) unsatisfactory findings regarding the appropriate time lag between patents and R and D.

In this study simple and simultaneous regressions will be run, considering patents as an input and/or output of R and D expenditures.

2.3.2 The R and D and Patents Statistics

Neither R and D nor patents are documented in a way appropriate for statistical compilation. Both – especially the R and D data – have to be reworked before they can be used for empirical research.

In Sweden, R and D statistics for the manufacturing sector have been published every second year since 1963. Since the patent data extends only to 1982, the use of these ten published years for R and D statistics seem to be rather insufficient for regression analysis, particularly when lags are involved. An alternative is interpolation of the missing (non-published) years. Apart from the reason noted above, there are two additional ones which favour the interpolation procedure. First, judging from the published years, (see figure 2.1 below) there have been no sharp variations in R and D expenditures.² This is not unexpected, as the labour cost share of R and D is approximately .90. Thus, if we assume that the likelihood of mass dismissals

¹ Hall, B.H., Griliches, Z., Hausman, J. A., Patents and R and D: Is there a lag? Working Paper No. 1454, NBER (1984), p. 3.

² It is important to mention at this point that the series used in this study denote R and D personnel costs and capital costs and not all R and D expenditures which include other costs as well, such as administration etc. Since the share of these costs has increased from almost 30 percent in early 1970s to 44 percent in 1983, the use of R and D expenditures would have given a steeper trend than that provided by this series.

or mass employment of R and D personnel for the non-published years is very low, one could accept the interpolated values as quite realistic. Second, an investigation of eight Swedish industrial groups, all of which have consistently published their R and D expenditures since the 1960s, has not revealed any significant variations in these expenditures from year to year. Since these industrial groups represent almost all sectors and account for nearly half of the total industrial R and D expenditures, we can consequently argue that such a "well-behaved" upward trend in R and D expenditures can be assumed to have taken place in the entire manufacturing sector as well.

There are three related decisions to be made: the choice of interpolation model, of deflationary index, and the choice between applying the trend model to nominal R and D expenditures or to deflated ones. Unfortunately, no specific R and D deflationary index exists. The Central Bureau of Statistics has argued that the implicit GNP deflationary index is the most relevant, and its use is therefore proposed.¹ Thus, our R and D expenditures are deflated accordingly, at 1975 prices.

Various trend forms have been fitted. Trend forms are preferred to averages in order to decrease the extremely high degree of correlation between the observed and the interpolated values which averages would cause.

A decision must be made whether to fit a trend form to the nominal values first and then deflate all values or fit a trend form to the deflated values first and then construct the missing years. To resolve this problem we have to introduce additional assumptions regarding the behaviour of firms. Do firms decide in advance the amount to be spent on R and D with no regard to price changes, or is their decision to undertake R and D shaped by the current and expected inflation rate? Do, in other words, firms suffer from money illusion or not? If firms make their decisions at the beginning of the year on some grounds, e. g., that a certain percent of their latest year's turnover or profit will be devoted to R and D expenditures, and they do not adjust that percent to the rate of inflation during the course of the year, the trend form should be fitted to the nominal values first. If, on the other hand, firms which make their decision at the beginning of the year are prepared to adjust their R and D policy to some extent so that the rate of inflation would be taken into account, the trend form should be fitted to the deflated values first. In general, both approaches would produce rather similar values for the interpolated years. However, there might be some interpolated years, such as 1976 and 1980, which would show higher variations in the values

¹ See Statistiska Meddelanden, Serie U:12, 1985 (SCB).

obtained from these approaches. For instance, the first approach would generate lower interpolated values for these two inflationary years and the second approach higher values.

Assuming no money illusion on the part of the firms, the second approach is applied here. Thus, after the existing values were deflated to 1975 prices, various trend forms were fitted. The best form, in terms of $\bar{R}^2$, was the following simple linear trend:

$$\begin{array}{ll} \text{RD} = 962.05 + 83.8545 \cdot T & \bar{R}^2 = .943 \\ (78.8) \quad (6.83) & \text{DW} = 1.74 \end{array}$$

where RD are R and D expenditures at 1975 prices and T is time (odd numbers from 1 to 19).

Thereafter, based on this trend form the missing years have been interpolated (even numbers from 2 to 20). The R and D expenditures – in million SEK at 1975 prices – together with patent applications and patents issued, are depicted in Figure 2.1. (Interpolated values are marked with stars).

Patent statistics refer to both patent applications (PA) applied for by Swedish firms and individuals, and patents issued (PI) to Swedish firms only.¹ The collection of patents issued to Swedish firms only, is justified because neither individuals nor foreign firms have undertaken any R and D activities in Sweden. However, foreign firms which operate in Sweden and have appeared with the Swedish characteristic AB (Ltd), such as Svenska Philips AB, IBM Svenska AB etc., have been included. These firms do undertake R and D activities in Sweden.

It would be desirable to separate patent applications made by firms from those made by individuals and relate only the former to the R and D expenditures, but time limitations made that impossible. The pattern that patent statistics have followed during the period 1963–1982 is also depicted in Figure 2.1.

2.3.3 R and D Leads, Patents Follow

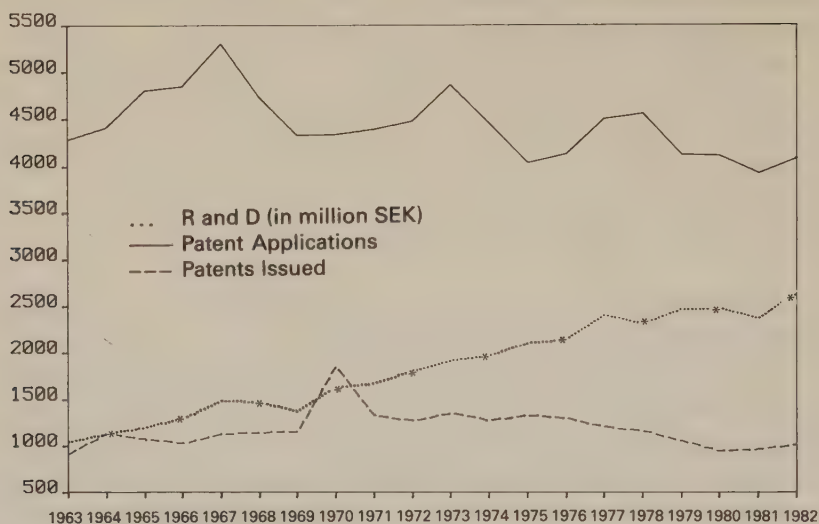
A very simple functional relationship of the Cobb-Douglas form between R and D expenditures and patents was assumed.

$$P_t = A e^{\lambda t} \cdot \text{RD}_{t-j}^{\alpha} \cdot v, \quad \log v \sim N(0, \sigma_v^2) \quad (1)$$

where: P_t denotes patent applications (PA) applied for by Swedish firms and individuals, or patents issued (PI) to Swedish firms only, RD_{t-j}

¹ In this chapter PI denotes patents issued to Swedish firms only, as opposed to chapter three where PI denotes the total number of patents issued in Sweden.

Figure 2.1. R and D, Patent Applications, and Patents Issued.



denotes R and D expenditures undertaken by the Swedish manufacturing sector during the period $t-j$ at 1975 prices, and t is time.

In our case, the a priori hypothesis is that the parameter α in equation (1) will be positive, that is the higher the R and D expenditures during a period $t-j$, the greater the number of patent applications and/or patents issued during period t , ceteris paribus.

2.3.3.1 Specification of the lag structure in R and D

Obviously R and D expenditures take time before they have an impact on output (in this case patents). But economic theory, although it recognizes this fact, does not provide us with the appropriate lag structure.

In order to get an idea, at least concerning the time period involved in R and D and patenting, which will help us to decide on the appropriate lag structure, the following points should be taken into account.

First, Mueller's (1966) estimates suggest a rectangular lag structure of four years between R and D and patents issued. Second, Pakes-Griliches (1984), contrary to what they expected, found a V type lag structure between R and D and patent applications. This implies large, significant, positive coefficients in the first and fifth year and very little effect of the interim years. However, due to the fact that R and D expenditures are

highly correlated from year to year, Pakes-Griliches argue that these estimates should be treated with caution. Third, in two studies, Heardsley (referred to by Mansfield (1980)), and Link (1981), the average time lag between R and D expenditures and the commercialization of the result of the project was found to be two to three years.¹ Finally, it should be pointed out that, more than 80 percent of R and D expenditures in Sweden are attributed to the development stage. This indicates that the time lag between R and D and patents should not be longer than that found in the USA where the share of R and D which is attributed to the development stage is lower.

Bearing all these in mind, we suggest that the maximum lag period between R and D and patents issued should not be more than five years, while the corresponding lag period between R and D and patent applications should be three to four years. (The average time period between a patent application and issuance is almost two years.)

The interpolation procedure applied to construct the non-published R and D expenditures has also created a high multicollinearity, which will affect the stability and significance of our estimates.

One way to avoid this multicollinearity is to transform the series, so that instead of simultaneously using all the suggested time lags, we use theoretical R and D series which are constructed based on some assumed lag structures.

To start with, the Almon scheme of polynomial lag was applied.² First, second and third degrees of the polynomial were tried and up to six lags were used with and without the end-point constraints, and with and without the time trend parameter.

Tables 2.1 and 2.2 below present the “best” Almon lag estimates. These estimates were regarded as “best” since they satisfied two restrictions. First, all the lag coefficients must be positive. Negative lag coefficients have no economic meaning in this “input-output” relationship. Second, the sum of all coefficients must approximate unity.

¹ Mansfield et. al. (1977), analyzing the effects of R and D expenditures on their diffusion period (until they reach the economic saturation level) revealed lags of ten, twenty and more years.

² The regressions were in run in TSP, Version 4.0. The computational method used by TSP is a modification of that originally proposed by Almon, and based on J.P. Cooper, “Two Approaches to Polynomial Distributed Lags Estimation: An Expository Note and Comment”, *The American Statistician*, June 1973. See TSP, Version 4.0, User’s Manual July, 1983. There are four options regarding the end-point constraints. Far (Near) – that is when the more recent (remote) values of X have greater influence on Y than more remote (recent) values – and Both (None) – that is when both (neither) recent and (nor) remote values of X have greater influence on Y.

Table 2.1: Almon lag estimates¹

(Linear with Far end-point Constraints.)

	log PA _t					
log RD _t	.6428*	.3556	.2689	.2330	.2147	.1986
	(.212)	(.185)	(.18)	(.189)	(.15)	(.15)
log RD _{t-1}		.1778	.1793	.1748	.1717	.1655
		(.092)	(.12)	(.142)	(.12)	(.12)
log RD _{t-2}			.0896	.1165	.1288	.1324
			(.06)	(.095)	(.09)	(.10)
log RD _{t-3}				.0583	.0859	.0993
				(.047)	(.06)	(.07)
log RD _{t-4}					.0429	.0662
					(.03)	(.05)
log RD _{t-5}						.0331
						(.025)
mean lag:	0	.333	.666	.100	1.33	1.66
		(.173)	(.458)	(.81)	(.95)	(1.27)
Sum of lag coeff.:	.6428*	.533	.537	.583	.644	.695
	(.212)	(.277)	(.369)	(.47)	(.46)	(.53)
λ	-.080*	-.072	-.071	-.070	-.068	-.067
	(.027)	(.037)	(.047)	(.039)	(.042)	(.04)
R ² :	.261	.131	.131	.231	.359	.531

¹ Standard errors are in parentheses

* Significant from zero at the .01 level of significance (two-tailed)

As is shown in the Tables below, the chosen Almon lag-scheme is linear. Estimates based on second and third order degrees of the polynomial were slightly inferior. Also, the “Far” end-point constraint, i. e. the more recent values of R and D have greater influence on patents than more remote values, was necessary to satisfy the restrictions stated above.

Table 2.2: Almon lag estimates¹

(Linear with Far end-point Constraints.)

	log PI_t					
log RD_t	1.649*	.9208	.6580	.4363	.3854	.3401
	(.563)	(.539)	(.51)	(.47)	(.41)	(.35)
log RD_{t-1}		.4604	.4387	.3272	.3083	.2834
		(.269)	(.34)	(.35)	(.33)	(.29)
log RD_{t-2}			.2193	.2181	.2312	.2267
			(.17)	(.23)	(.25)	(.23)
log RD_{t-3}				.1091	.1541	.1700
				(.11)	(.16)	(.18)
log RD_{t-4}					.0771	.1134
					(.08)	(.11)
log RD_{t-5}						.0567
						(.05)
mean lag:	0	.33	.666	1.00	1.33	1.66
		(.195)	(.52)	(1.08)	(1.4)	(1.7)
Sum of lag coeff.:	1.649*	1.38	1.316	1.09	1.56	1.19
	(.563)	(.80)	(1.02)	(1.17)	(1.25)	(1.7)
λ	-.08*	-.072	-.071	-.07	-.068	-.067
	(.027)	(.037)	(.047)	(.039)	(.042)	(.04)
$\bar{R}^2$:	.261	.131	.131	.231	.359	.531

¹ Standard errors are in parentheses

* Significant from zero at the .01 level of significance (two-tailed)

What we observe in these tables is that it is not clear that any lag would significantly improve the estimates obtained from the non-lag estimation. None of the lag coefficients is different from zero. In the case of patent applications, not only the lag coefficients were insignificant, but their sum was not improved either. It is also of interest to mention that when lags were included, the non-lag coefficient became insignificant. The non-lag coefficient remained strongly positive in some cases, when there was no end-point constraint. However, in these cases, our restrictions were violated since the coefficients of higher lags became negative and the sum of lag coefficients was very low or even negative.

Because the sum of the lag coefficients did not approximate unity, these estimates were normalized, so that their sum would equal unity, and a new (weighted) R and D series was constructed based on these normalized

values. Regressions of patent applications and patents issues against that new R and D were run to test if the estimated coefficients of this weighted R and D would be positive. Although we expected better estimates, again, as previously, the estimated coefficients were not significant from zero. In addition, the trend term has never been significant from zero. When this non-significant trend term was deleted from the regressions, strongly negative coefficients appear almost everywhere.

Thus, we may argue that our statistics reveal no economically reasonable time lag between R and D and patents. On the contrary, the non-lag relationship between R and D and patent applications reveals positive but decreasing returns to R and D, while a similar relationship between R and D and patents issued to Swedish companies only reveals increasing returns.

Before we turn to the explanation of these unexpected negative lag coefficients, it would be interesting to present the estimates of the reverse and the contemporaneous relationships.

2.3.4 Patents Lead, R and D Follows

The discovery that lagged R and D does not appear to generate patents necessitates the investigation of the reverse relationship.

Again, the functional relationship between patents and R and D expenditures was assumed to be of the Cobb-Douglas form.

$$RD_t = Be^{\lambda} P_{t-j}^{\beta} u, \quad \log u \sim N(0, \sigma_u^2) \quad (2)$$

where, as previously, RD_t denotes R and D expenditures at 1975 prices, undertaken during the period t ; P_{t-j} denotes patent applications (PA) and issued (PI) during the period $t-j$; and t is time.

From the econometric point of view, if the interpolated dependent variable RD involves measurement errors, the specification form (2) is better than the reverse form (1). As is well known, (see for instance Kmenta (1971)) any measurement errors in the dependent variable are assumed to be included in the random variable u , and as a consequence the estimates remain unbiased and efficient. On the other hand, the existence of measurement errors in the independent variable – that is estimation of equation (1) where the interpolated variable RD is considered as independent – makes the OLS estimates biased and inefficient.

Tables 2.3 and 2.4 below present the “best” Almon lag estimates for patent applications and patents issued.

In terms of significance in the lag coefficients and of the explanatory power, these estimates are better than those provided by equation (1). In addition, it is worth emphasizing that the significantly positive lag coefficients of patents (especially patents issued) remained significant and did not

weaken, after the introduction of the time trend which was also strongly positive. To put it differently: Tables 2.3 and 2.4 show a complementarity between the time parameter and patents in contradiction to Tables 2.1 and 2.2, where the time parameter and the R and D expenditures are considered as substitutes for each other.

Table 2.3: Almon lag estimates¹

(Linear with Far end-point Constraints.)

	log RD _t					
log PA _t	.5458*	.3647**	.2709	.1743	.0593	-.0040
	(.18)	(.158)	(.172)	(.20)	(.259)	(.33)
log PA _{t-1}		.1823**	.1806	.1308	.0474	-.0033
		(.079)	(.114)	(.15)	(.208)	(.27)
log PA _{t-2}			.0903	.0872	.0356	-.0026
			(.057)	(.10)	(.156)	(.22)
log PA _{t-3}				.0436	.0237	-.0020
				(.08)	(.104)	(.16)
log PA _{t-4}					.0119	-.0013
					(.052)	(.11)
log PA _{t-5}						.0007
						(.05)
mean lag:	0	.333**	.666	1.00	1.33	0
		(.144)	(.423)	(1.15)	(5.8)	
Sum of						
lag coeff.:	.5458*	.547**	.542	.346	.178	-.0138
	(.18)	(.237)	(.344)	(.5)	(.78)	(1.16)
λ	.052*	.051*	.050*	.048*	.044*	.043*
	(.002)	(.003)	(.004)	(.005)	(.008)	(.001)
R ² :	.972	.965	.954	.942	.928	.919

¹ Standard errors are in parentheses

* Significant from zero at the .01 level of significance (two-tailed)

**Significant from zero at the .05 level of significance (two-tailed)

Table 2.4: Almon lag estimates¹

(Linear with Far end-point Constraints.)

	log RD _t					
log PI _t	.2033*	.1498**	.1196**	.0992**	.090**	.1224*
	(.0694)	(.0547)	(.0446)	(.0392)	(.038)	(.031)
log PI _{t-1}		.0749**	.0797**	.0744**	.072**	.1020*
		(.0273)	(.0298)	(.0294)	(.031)	(.026)
log PI _{t-2}			.0399**	.0496**	.054**	.0816*
			(.0149)	(.0196)	(.023)	(.021)
log PI _{t-3}				.0248**	.036**	.0612*
				(.0098)	(.015)	(.016)
log PI _{t-4}					.018**	.0408*
					(.008)	(.010)
log PI _{t-5}						.0204*
						(.005)
mean lag:	0	.333**	.666**	1.00**	1.33**	1.66*
		(.121)	(.248)	(.395)	(.569)	(.428)
Sum of						
lag coeff.:	.2033*	.2246**	.239**	.248**	.27**	.428*
	(.0694)	(.082)	(.089)	(.098)	(.115)	(.11)
λ	.048*	.047*	.046*	.045*	.044*	.048*
	(.002)	(.002)	(.002)	(.002)	(.003)	(.002)
R ² :	.971	.968	.964	.958	.949	.964

¹ Standard errors are in parentheses

* Significant from zero at the .01 level of significance (two-tailed)

**Significant from zero at the .05 level of significance (two-tailed)

Evaluating the effect of lagged patents on R and D expenditures, we see (as expected) that patents issued seem to generate both more and longer run R and D expenditures than patent applications. This can be explained as follows. First, as mentioned earlier, patents issued denote patent approvals only to Swedish firms which are assumed to undertake R and D activities, while patent applications do not separate individuals from firms. Obviously, the share of patent applications applied for by individuals might not be constant over time. Second, assuming that the number of patents issued to firms is a better indicator both of the ability to invent and the quality of inventions (at least to satisfy the requirements of the patent authorities), it is understandable why companies undertake R and D expenditures to a larger extent when their patent applications are considered favourably. Similarly,

this can explain why firms seem to be reluctant to continue their R and D activities in order to improve or develop a patent application which has been rejected. However, it must be noted that there is no guarantee that all patents issued to firms have been originally applied for by them. The possibility that firms might have purchased an original patent from individuals or from abroad and then applied for some subsequent patents is not excluded.

2.3.5 A Simultaneous Relationship between R and D and Patents

The findings of the last two sections have revealed that if patents do not lead R and D expenditures, they at least determine and are being determined by R and D expenditures. However, if such a simultaneous relationship exists, the application of least squares to single equations might yield biased and inconsistent estimates (see for instance Kmenta (1971)). As a consequence, we are not certain if, for instance, the non-lag coefficients between R and D and patents are positive, as single equation estimates have indicated. Thus, to avoid such a simultaneous equation bias, it is appropriate to estimate these equations jointly.

The problem of identification becomes more serious when dealing with simultaneous system. In an underidentified system, the estimates may become biased and inefficient. Also, the estimates of parameters measured in samples may relate not to the model in question but to another model or to a mixture of models. Thus, care should be taken to have a completely identified system.

The following system is completely identified¹

$$\ln P = \alpha_0 + \alpha_1 \ln RD + \alpha_2 \ln RD_{-1} + \alpha_3 t + u_t$$

$$\ln RD = \beta_0 + \beta_1 \ln P + \beta_2 \ln P_{-1} + \beta_3 t + v_s$$

where P, RD and t as before, and $\text{cov}(u_t, v_s) = \begin{matrix} \sigma_{uv} & \text{if } t = s \\ 0 & \text{if } t \neq s. \end{matrix}$

Lagged variables appear as predetermined variables in these equations. Note that without the lagged variables – RD₋₁ for the first equation and P₋₁ for the second – the system would be underidentified. Obviously lagged

¹ The order condition for identification is applied. It is expressed as:

$$(K-M) = (G-1)$$

where: G = total number of equations (=total number of endogenous variables).
K = number of total variables in the model (endogenous and predetermined),
M = number of variables, endogenous and exogenous, included in a particular equation.

variables of higher order could also be included in our equations without affecting the identification of the system. Similarly, the time trend could have been excluded without affecting the identification of the system. But again, based on our single equation estimates, the time trend was included in both equations.

Table 2.5 below presents the seemingly unrelated regression estimates (see Zellner (1962)) for patent applications and patents issued together with R and D. Two alternative systems of equations are depicted, one with a lag of first order (1a, 2a) and one with three order lags (1b, 2b).

Table 2.5: Simultaneous Estimates¹

$\ln PA = 2.24 + .823*\ln RD + .071 \ln RD_{-1} - .051*t$	
(1.5) (.19) (.18) (.01)	(1a)
$\ln RD = .393 + .776*\ln PA + .009 \ln PA_{-1} + .054*t$	
(1.6) (.18) (.05) (.002)	
$\ln PI = -6.4 + 2.32*\ln RD - .325 \ln RD_{-1} - .098*t$	
(4.1) (.52) (.5) (.03)	(2a)
$\ln RD = 4.7* + .244*\ln PI + .074 \ln PI_1 + .048*t$	
(.48) (.071) (.06) (.002)	
$\ln PA = 6.3** + .780*\ln RD + .13 \ln RD_{-1} - .29 \ln RD_{-2} - .31 \ln RD_{-3} - .02 t$	
(2.4) (.19) (.18) (.22) (.23) (.01)	
$\ln RD = -1.3 + .835*\ln PA - .07 \ln PA_{-1} + .08 \ln PA_{-2} + .13 \ln PA_{-3} + .05*t$	(1b)
(4.5) (.26) (.23) (.23) (.23) (.005)	
$\ln PI = -13** + 1.61*\ln RD - .78 \ln RD_{-1} + .55 \ln RD_{-2} + 1.7*\ln RD_{-3} - .16*t$	
(5.7) (.45) (.46) (.54) (.56) (.04)	(2b)
$\ln RD = 4.5* + .120 \ln PI + .04 \ln PI_1 + .09 \ln PI_2 + .09 \ln PI_3 + .04*t$	
(.6) (.07) (.08) (.07) (.08) (.002)	

¹ Standard errors are in parentheses.

* Significant from zero at the .01 level of significance (two-tailed)

** Significant from zero at the .05 level of significance (two-tailed)

The non-lagged simultaneous estimates and the time-trend parameters remained strongly significant as in the single equation estimates. On the other hand, the significance which existed in the lagged patents from the single equations (see Tables 2.3 and 2.4) disappeared. Only a weak positive effect remained. Observe also in (2b) that the non-lagged patents issued become non-significant as well. The strongly positive effect of RD₋₃ on patents issued should also be mentioned. These two effects are opposite to those obtained in Tables 2.2 and 2.4 previously. (It was found then that lagged R and D did not generate patents issued – Table 2.2 – while lagged patents issued seem to be positively correlated to R and D – Table. 2.4).

We might therefore conclude that a simultaneous positive relationship between R and D and patent applications seems to be more clear than that between R and D and patents issued.

2.4 An Attempt to Evaluate the Patent Statistics in Sweden during the 1970s

The unclear simultaneous relationship between R and D and patents issued, the rejection of the hypothesis that lagged R and D generates patents issued in Sweden (at least in single regression equations), the appearance of some unexpected negative effects (at least in separate and simultaneous lags), and the generally decreasing returns to patents issued with respect to the lagged and non-lagged R and D (at least in single regression equations), leads us to investigate more thoroughly the measures of patents issued and R and D expenditures. This section investigates the “quality” of Swedish patents, while in the Appendix A an attempt is made to evaluate the impact of R and D on productivity.

The quantity of patents does not reveal anything at all about their “quality”. A patent of a “very high quality” might be equal to hundreds of simple patents. Is it therefore the “quality” or the technological and economic opportunities of inventions that matter and not simply the number of inventions. If today’s patents are of a higher “quality” than yesterday’s, and as a consequence they require higher R and D expenditures, decreasing returns to R and D and non-significant effects of lagged R and D are no longer surprising.

Researchers who have dealt with patents tend to deliberately “neglect” the assumption of quality of patents. This is easy to understand since it requires an enormous amount of time and high technological qualifications to evaluate all patents issued annually.

The question of interest here is if we can accept the “heroic” assumption that the quality of patents has remained unchanged. And if not, how can we test the assumption of quality and how can quality be measured?

A simple attempt has been made to test for the quality of patents issued by classifying them into three technological groups, high (H), medium (M) and low (L), during the peak patenting period (1969–1971) and the bottom patenting period (1978–1980).

This classification is an attempt to modify the rather unrealistic assumption that all patents are of the same quality, and instead employ the more realistic one of differentiating quality according to technological opportunity. We assume that *all* the patents within the H group are superior to all the patents within the M group and that those are superior to *all* the patents in the L group. This is a more realistic assumption but it is of course still a rather restrictive one.

2.4.1 The data set

A sample of eighteen Swedish industrial groups (parent company and subsidiaries) was chosen.¹ The sample is selected and not random, which can be justified in two ways. First, all these groups are highly innovative. The share of patents issued to these groups was 44 percent during the period 1969–1971 and 41 percent during the period 1978–1980. Secondly, all these groups have been very successful and are considered to play a major part in the Swedish economy. Together with their subsidiaries they constitute roughly one third of total Swedish manufacturing in terms of employment, value-added and assets. Therefore, since the aim of this section is to test if patents issued have improved in quality for the entire manufacturing sector, all these firms should be included. It would be more desirable to measure and classify all the patents issued to Swedish firms but this is a very cumbersome task since patent statistics are not organized for the purpose of economic analysis. For instance, Swedish patent statistics are not collected according to the standard industry and product classifications. In addition the classification employed by them during the first period was not similar to that of the second period. New terminology and both higher and lower aggregation levels between various sectors characterizes the second period.

2.4.2 Composition of Patents

After data for patents issued have been obtained, they were classified into twenty groups according to the international patent classification. Highly technological opportunity groups (H) are: electricity-electronics, instruments, chemicals and allied products, weapons and ammunition and nuclear technology. Medium technological opportunity (M) are: transport, metal works, lightning and heating, general machinery, metallurgy, housing equipment, construction, methods for separation and mixing, mining technology, machinery and pumps, printing and ornamentation and health and recreation. Low technological opportunity groups (L) are: paper, food, tobacco, agriculture and fishery.

¹ These groups are: AGA, ALFA LAVAL, ASEA, ASTRA, ATLAS COPCO, BAHCO, BOFORS, ELECTROLUX, ESAB, ERICSSON, FLÄKTFABRIKEN, KEMA NOBEL, PHARMACIA, SAAB-SCANIA, SANDVIK, SCA, SKF and SWEDISH MATCH. Together with their subsidiaries they amount to almost 100 firms. VOLVO, the largest Swedish company was excluded from the sample because the propensity to patent in the automobile industry is very low. For instance, Scherer, F.M., in *Demand Pull and Technological Invention: Schmookler Revisited*, *Journal of Indust. Econ.* 3, pp. 225–37 (1982) argues that this industry stresses styling and model testing rather than the creation of new mechanical features. On the contrary, SAAB-SCANIA which produces computers and air-crafts – where patenting is higher – was included.

Table 2.6 below, depicts the number and percentages of patents classified into twenty different sectors during 1969–1971 and 1978–1980. Column 1 shows the class to which they belong and the corresponding technological groups are given in parentheses. Columns 2 and 4 show the number of patents during the first and second period respectively. Columns 3 and 5 show the corresponding shares of patents to the total patents for these periods.

Before we comment on this Table, it should be mentioned that, due to the adjustment of the classification of patents between the first and second periods there is a residual of 89 patents in the first period which remain unclassified in the second. All these “random” patents were classified as either L or M and not H, since all patents which belong to H have been extensively investigated.

The general conclusion which can be drawn from Table 2.6 is that the share of high quality patents has fallen from 51.2 percent in 1969–1971 to 43.4 percent in 1978–1980. The absolute and/or the relative increase in the patents in the area of nuclear technology, weapons and ammunition and instruments could not offset the absolute and relative decline in the sectors of electricity and electronics, and chemical and allied products.

Similarly, the share of lower quality patents has fallen from 9.3 percent to 3 percent, if the random unclassified patents are considered as L, and from 4.8 percent to 2.3 percent if these patents are considered as M. In both cases, the share of medium quality patents increased and the decline in the share of high quality patents is larger than the decline in the share of lower quality ones.

That overall quality, and not only the quantity, of patents has declined during the second period, is also substantiated when we construct a technological index under the assumption that the differences in weight between H and M sectors are as high as between M and L ones. For instance, when we assign the value two for patents which belong to H sectors, the value one for patents which are classified as M and the value zero for those which are classified as L, we obtain a 43 percent increase in patents in the first period (a 47 percent increase when the 89 unclassified patents are classified as M), and a 40 percent increase of patents in the second period. Thus, given the stated assumption, the use of a quality weights index increases the gap between the two periods.

Therefore, if our restrictive assumption that, on the average, patents in the same group are of approximately the same quality for both periods and consistently superior or inferior to patents in another group is correct, there seems to be no improvement in the quality of patents between 1969–71 and 1978–80. In other words, since the quantity of patents issued to these

Table 2.6: The Classification of Patents Issued

Class	No. of patents 1969-71	% of total	No. of patents 1978-80	% of total
H ¹⁻⁵ (H)	590	31.18	244 (1)	18.91
G ¹⁻¹² (H)	179	9.46	141 (3)	10.93
C ¹⁻¹⁴ (H)	164	8.66	80 (6)	6.2
F ⁴¹⁻⁴² (H)	33	1.74	56 (9)	4.34
G ²¹ (H)	6	.31	39 (11)	3.02
B ⁶⁰⁻⁶⁸ (M)	152	8.03	122 (4)	9.45
B ²¹⁻³² (M)	119	6.28	144 (2)	11.16
F ²¹⁻²⁸ (M)	114	6.02	85 (5)	6.58
F ¹⁵⁻¹⁷ (M)	106	5.60	73 (7)	5.65
C ²¹⁻²³ (M)	79	4.17	35 (12)	2.71
A ⁴⁷ (M)	44	2.32	26 (14)	2.01
E ¹⁻⁶ (M)	32	1.69	23 (17)	1.78
B ¹⁻⁸ (M)	30	1.58	72 (8)	5.58
E ²¹ (M)	23	1.21	26 (14)	2.01
F ¹⁻⁴ (M)	20	1.05	41 (10)	3.17
B ⁴¹⁻⁴⁴ (M)	17	.89	9 (19)	.69
A ⁶¹⁻⁶³ (M)	5	.26	31 (13)	2.40
D ²¹ (L)	48	2.53	24 (16)	1.86
A ²¹⁻²⁴ (L)	22	1.16	3 (20)	.07
A ¹ (L)	20	1.05	13 (18)	1.00
Non-classified	89	4.54	3	.07
	1892	100	1290	100

H¹⁻⁵ = Electricity and Electronics, G¹⁻¹² = Instruments, C¹⁻¹⁴ = Chemicals and Allied Products, B⁶⁰⁻⁶⁸ = Metal works, B²¹⁻³² = Transport, F²¹⁻²⁸ = Lighting and Heating, F¹⁵⁻¹⁷ = General Machinery, C²¹⁻²³ = Metallurgy, D²¹ = Paper, A⁴⁷ = Housing equipment, F⁴¹⁻⁴² = Weapons and Ammunition, E¹⁻⁶ = Construction, B¹⁻⁸ = Mixing and Separation Methods, E²¹ = Mining Technology, A²¹⁻²⁴, Food and Tobacco, A¹ = Agriculture and Fishery, F¹⁻⁴ = Machinery and Pumps, B³¹⁻⁴⁴ = Printing and Ornamentation, G²¹ = Nuclear Technology, A⁶¹⁻⁶³ = Health and Recreation.

companies fell by 68 percent between these two periods, one must accordingly argue that there are some patents classified into L or M sectors whose technological opportunities have been much higher than those classified into the H sector, if the quality weights index is to remain constant.

2.4.3 Other studies

It was mentioned earlier that studies evaluating the quality of technology are very rare. In Sweden, two studies may be considered as rather relevant to our findings and are therefore worth mentioning.

The first, which addresses questions similar to ours, was undertaken in 1983, at the Chalmers University of Technology in Gothenburg.¹ The study focuses on major innovations instead of patents. Their definition of major innovations is made in economic terms, and thus is considered to be any innovation obtained during the period of investigation (1945–1980) which has generated sales of at least 20 million SEK per year (at 1980 prices) until 1980. The peak point was reached in 1967 (7 innovations) and thereafter started a downward trend with some fluctuations. The shape of the trend for major innovations is similar to the trend for our patents. Another of their findings also substantiates our results regarding the lack of improvement in the quality of patents. There have been 11 major innovations since 1965 which belong to the categories chemicals and allied products, and all of them occurred before 1973. Also, 70 percent of the 25 major innovations which are classified as electricity and machinery were obtained before 1973, and none after 1977. Finally, 87 out of 100 major innovations had occurred by 1973. All these findings suggest that major innovations have been declining during the 1970s. This indicates that inventions from the 1970s are not qualitatively better than inventions from the prior decade(s).

The second study,² which is less comparable to ours because it investigates the problem of Sweden's relative technological position over the last four decades, comes to a different conclusion. To quote the researchers: "... Sweden has been and is technologically a leader in relatively few areas, but technically among the leaders in a large number of industrial branches" (p. 143; translation from the original). However, the result of that study does not provide any clear-cut proof regarding the improvement or the deterioration of the quality of inventions in Sweden. If the number and the quality of inventions in other countries have declined relatively more than

¹ McQueen, D. H., and J. T. Wallmark, 100 Viktiga Innovationer i Sverige, 1945–1980, STU, Stockholm, 1983.

² Carlsson, B. et. al., *Teknik och Industristruktur: -70-talets ekonomiska kris i historisk belysning*, IUI, Stockholm, 1979.

in Sweden, then Sweden will still hold a technologically high position. The results of our study, however, do not reveal any loss in Sweden's technological position; they simply show a lack of improvement in the quality of its inventions during the 1970s.

2.5 Conclusions

In the beginning of this chapter we argued that all measures suggested to approximate innovation are rather deficient. It is all the more necessary to analyze the most commonly used proxies, R and D and patents. If one could ascertain a strong correlation between R and D and patents, then the results of our study would be unaffected by the way we measured innovation.

Unfortunately, simple correlation coefficients between R and D and patents (both applications and those issued) were found to be not only small in absolute size but negative as well (varying between $-.2$ to $-.4$). This result necessitated a detailed investigation of the possible relationship between R and D and patents. Both single regression equations and simultaneous system equations were run. Similarly, various Almon lag structures were applied to account for the apparent differences in timing between R and D and patents.

A simultaneous relationship seems to prevail only in the case of R and D and patent applications. On the other hand, the relationship between R and D and patents issued is quite unclear. In single regression equations, no significant effects appear between patents issued and lagged R and D expenditures, while positive effects appear in the reverse relationship.

This result led to a further investigation of the patents issued and R and D expenditures. As far as patents issued are concerned, an attempt was made to test for their "quality" since the number of patents issued to Swedish firms declined during the 1970s. Contrary to what was expected, the share of high quality patents has also declined between 1969–71 and 1978–80.

The relationship between R and D and productivity growth (see Appendix A), has also revealed some surprising results. The strongly positive correlation which can be observed during the period 1963–1973 turns to negative during the period 1974–1983!

Thus, apart from the externalities and the problem of measuring R and D, patents and productivity, the small and sometimes negative correlation coefficients between lagged R and D and patents or productivity could be viewed as a decline of R and D productivity.

As an illustration, we can report some characteristic numbers. In 1970, the average R and D expenditures per issued patent were .8 million SEK and in 1980 they increased to 2.5 millions (in 1975 prices). Similarly, in 1970, a patent issued required (on the average) 9 full-time researchers, and ten

years later, a patent of approximately the same quality required 23 full-time researchers. This final evidence is indeed in full accordance with an interesting study undertaken by Evenson (1984). According to him, patenting per scientist and engineer (and per R and D dollar) decreased from the late 1960s to the late 1970s in almost all of the fifty countries for which data are available.

Our final conclusion then is that patent statistics can be used as an unbiased measure of the inventive activities in Sweden.

Chapter 3

Innovation, Growth and Cycles in Sweden

3.1 Introduction

After having discussed in chapter one the direct relationship or causality between innovations, economic growth and business cycles, and in the previous chapter the measurement problems of innovations, we come to a central issue of the thesis.

The implication of the Schumpeterian theory discussed in the first chapter is that cycles arise because innovations are not evenly distributed through time. The kind of cycle will depend on the degree of significance of innovations and/or the degree of their clustering. If, on the other hand, innovations appear continuous steady-state economic growth seems to be more likely than business cycles.

Based mainly on patent statistics and secondly on major innovations, we will attempt to test if the causal mechanism runs from innovations to growth through cycles as the Schumpeterian theory argues or from growth to innovation as the Schmookler (1966) findings suggest.

It is, however, not only the approximation of innovations by patent statistics which might be unclear, it is also the appropriate identification of growth and business cycles which might be difficult to ascertain.

It was mentioned in the first chapter that many economists have identified business cycles by fluctuations in investment.

Thus, by investigating investment figures, one derives information about output (or income), inflation and employment, that is the most interesting variables underlying economic activity. Apart from Freeman-Clark-Soete who dare to question the positive relationship between investment and employment or output and employment, all other theorists continue to accept these relationships and are satisfied with looking at only investment or output figures. There is, however, a deeper disagreement among economists (not only among business cycle or long wave economists) which refers to the determinants of investment. Going back to Wicksell (1936) and Keynes (1936), we find that the interest rate is identified as a major argument. Thus, if the expected yield – what Wicksell called the “natural rate” and Keynes christened “marginal efficiency of capital” – is larger (smaller) than the interest rate or market rate, then investments are (not) worth undertaking. Since then, numerous models based on the well known IS-LM techniques have been constructed in order to explain how different

economic policies will influence the interest rate and as a consequence the rate of investment. Empirical studies, however, show that capacity utilization, profits, stocks of government securities, accrued tax liability, debt capacity, change in profits, capital stock, value of output divided by price of capital services and percentage change in the securities price index (except for the interest rate) are significant determinants of investment (Praski, 1978). A survey of the relevant literature would undoubtedly reveal some other determinants as well.

The index of industrial production, the index of wholesale prices, the production of pig iron, railroad car loadings and ton miles, the volume of employment and national product are also frequently used. Among them, output series are probably the least deficient indicator of business cycles and economic growth (Acheinstein, 1950). Investment and value added statistics will be principally used in this study.

3.2 Economic Fluctuations in Sweden

Many leading Swedish researchers¹ deny the existence of long waves in Sweden. Almost all of them argue that, although economic crises in this country have followed the general pattern of all industrial countries, the amplitude of swings has been smaller and shorter. There have been some downward periods in Sweden, but they should be considered as short and weak interruptions in a steady process of expansion.

Only a foreign investigator, Mitchell (1981) – referred to in van Duijn (1983) – argues that Kondratieff long waves might, to some extent have appeared in Sweden as well as elsewhere. Thus, according to Mitchell, the upswing of the third Kondratieff cycle occurred during the period 1894–1913, a period which is characterized by Swedish researchers as the beginning of a new wave of industrialization in this country. Similarly, the period 1948–1973 was identified with the upswing of the fourth Kondratieff wave.

Table 3.1 below summarizes Sweden's economic growth since its industrialization period – which is dated around the end of 1860s.

¹ Dahmén (1950), Lundberg (1957, 1968), Jörberg (1961), Jungenfelt (1966), Lindbeck (1975), Krantz-Nilsson (1975), Bentzel (1978, 1979).

*Table 3.1: Actual Rates of Growth of Swedish Gross National Product
(Average of 5 years).*

Period	Rate	Period	Rate
1870–1875	4.4	1925–1930	4.9
1875–1880	2.4	1930–1935	0.8
1880–1885	1.7	1935–1940	1.8
1885–1890	1.7	1940–1945	3.0
1890–1895	3.4	1945–1950	4.9
1895–1900	3.1	1950–1955	1.7
1900–1905	2.6	1955–1960	3.3
1905–1910	4.0	1960–1965	4.8
1910–1915	2.1	1965–1970	3.2
1915–1920	0.6	1970–1975	2.0
1920–1925	4.9	1975–1980	0.6

Source: Bentzel, R., (1979).

Although these rates of growth refer to GNP, other rates of growth show a similar pattern, i. e. long upward periods followed by very short downward ones. Consequently, the existence of business cycles regular in shape and duration seem doubtful in the case of Sweden.

Regarding the downward periods, it is generally accepted that crises appeared in the late 1870s and the beginning of 1880s, in 1916–18, 1921–22, 1930–32, in the early 1950s and – most recently – from the middle of the 1970s. The dispute arises whether to classify these crises as major or minor ones. Dahmén (1950), for instance, considers the crises of the late 1870s, of 1921–22 and 1930–32 as major ones. These periods would be classified as depressions when utilizing a variety of business cycle indicators – such as unemployment rates, price indices and trade figures. On the other hand, the crisis of 1916–18, which according to Bentzel was rather severe, is classified by Lindbeck (1975) as minor. Finally, there will be many who would consider the most recent crisis as rather severe and persistent because there appeared symptoms of severe imbalances in the economy such as deficits in the budget and in the balance of payments, stagflation, and decline of investment, of exports, of productivity, of industrial output and of real income.

Various views have been provided to explain the economic fluctuations in Sweden.

It is generally accepted that Sweden, as a small open economy, has been greatly affected by various cyclical oscillations which have occurred in other industrial countries. A decline in its exports, due to the world-wide recessions and depressions which appear sporadically, will negatively affect its

investment, production, employment, income etc. van Duijn (1983), summarizing the long wave chronologies according to various authors, tends to support the hypothesis that the lower points of the waves in many industrial countries coincide with those in Sweden, namely in 1895 and 1948, as do the upper points in 1913 and 1970.

This argument, moreover, seems to be relevant to explain short cycles and not long waves, because short cycles are expected to be more synchronized than long waves. In addition, if Swedish business cycles were completely dependent on the cycles which have taken place in other industrial countries, the amplitude of its swings would have been similar, that is both larger and longer. One should, therefore, look for other factors to explain the rather smooth variations in Swedish cycles. Many factors have been mentioned. Active stabilization policies, absence of world wars, abundance of natural resources, peaceful wage negotiations between trade unions and management, political stability, high degree of homogeneity and high educational standards in the population, weather conditions and technical innovations are the most commonly mentioned factors.

Lundberg (1957), the most prominent Keynesian economist in Sweden, offered a traditional answer to this question. According to him, successful economic policy lessens the effect of economic crises and accentuates economic growth, while incorrect economic policy accentuates crises and dampens economic growth. The economic policies of the 1920s, for instance, should be condemned as “reactionary”, while the policies pursued after 1933 should be considered as more “progressive”.¹ Although his explanation seems very persuasive, one might wonder if it provides necessary and sufficient conditions to explain the smoothness of business cycles in this country.

If economic policy is granted such large significance, one would question why the 1920s was not characterized by downward trends. Similarly, one would wonder why the traditional expansive Keynesian policies implemented during the 1970s did not bring about the desirable effects.

Lundberg himself, seems to provide a secondary explanation to the first question, when he remarks that despite the “reactionary” economic policies of the 1920s, “... industrial development proceeded in an atmosphere of great activity in the establishment of fresh enterprises”.²

¹ Lundberg here talks about “reactionary” and “progressive” policies and not only about Keynesian policies. According to him, there was no talk of long-term economic stagnation in Sweden in the 1930s. And since Keynesianism was the suggested remedy of a stagnant economy, Sweden did not need such a remedy simply because it did not suffer from stagnation. See Lundberg, E., *Business Cycles and Economic Policy*, (1957), p. 7–8 and 122.

² Lundberg, op. cit. p. 18.

The 1916–1918 crisis and the crisis which started in the early 1950s are regarded as true external distortions, and were caused by the first World War and the Korean war respectively (see for instance Lindbeck, 1975).

The international depression, the oil-crisis, cost-pushing and demand-pulling inflation, and the explosion of the public sector are the most frequently discussed factors which prompted the recent crisis.

3.3 Innovations and Swedish Economic Growth

Innovations have always been considered a significant factor contributing to Swedish economic growth. There is, indeed, a clear consensus on this point among Swedish researchers. Jörberg (1961), for instance, argues that when Sweden was affected by the international depression during the first decades of industrialization, it was the establishment of new industries that drove up the expansion to a higher level and consequently ameliorated the crises. Lundberg (1957), also – as was pointed out previously – explains the high growth rates of the 1920s through the establishment of fresh enterprises despite the “reactionary” economic policies which were implemented during that period.

Although all researchers have mentioned the role of innovations, it was Dahmén (1950) who succeeded in providing a causal analysis of Swedish industrial development in terms of technical innovation. By examining the period 1919–1939, he supported the existence of the Schumpeterian “creative-destructive” mechanism, that is that innovations have caused both positive effects such as the creation and development of new products, processes, markets and industrial sectors and negative ones such as the decline and termination of outdated products, markets and industries.

The crisis of the 1970s can also be explained through a Schumpeterian mechanism. According to Dahmén (1980) the “creative-destructive” mechanism ceased to work during the end of the 1960s and the 1970s. New products, processes, companies and sectors were lacking or at least they were not created at the same rate as previously. Consequently, the destructive part of this mechanism could not operate. Old and traditional sectors and products had to be protected at any price, a policy which proved to be detrimental.

Retesting and renewing such an enormous study is very difficult. In addition, one runs the risk of retelling known stories rather than making an original contribution. On the other hand, it is easy to motivate that a new version of this study is a worthwhile endeavor. It is not only the time period which differs from Dahmén’s study, but a slightly different approach is also utilized. Here, a disaggregated and detailed investigation of all industrial sectors will not be undertaken. By examining the entire economy in terms of

innovations and economic decline in the way suggested in the first chapter, we can shed more light on the crisis of the 1970s.

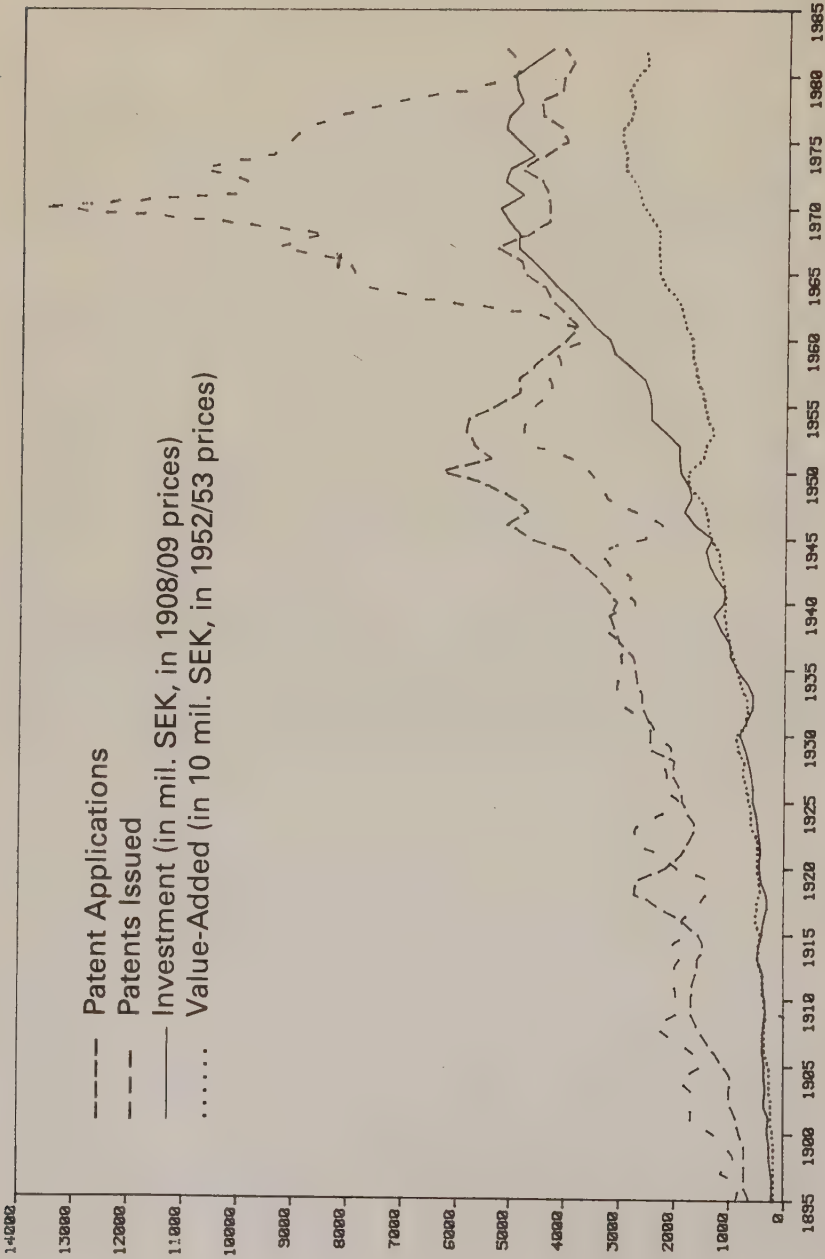
Considering innovations as one of the major determinants of economic growth in Sweden is not an accidental choice. Their impact is recognized by everyone, but the degree of significance which is assigned to them by researchers is often rather low. By studying the role of innovations we do not necessarily deny the effect of all traditional factors such as money, interest rates, taxes etc. This approach should instead be viewed as a complement and not a contradiction to traditional economic explanations.

Figure 3.1 below gives a general idea regarding the correlation between innovations (patent applications made by Swedes and patents issued by the S.P.R.O.) and economic growth (measured by investment and value-added statistics) (see also Appendix 2.1).

Apart from the rather good correlation between innovation and growth, a rather clear relationship between the crisis of the 1970s and the decline of innovations is also shown. For instance, patent applications reached a peak in 1967 and a low point in 1981. During that period, the decline in the number of patent applications is almost 1400 patents. Patents issued also reached a peak in 1970 and a low point in 1981. In twelve years that decline has amounted to almost 9000 patents. Similar peaks and troughs are also obtained when we look at the patents issued to Swedish firms only (Figure 2.1).

While all these time series reveal relatively similar trends, a further investigation of Figure 3.1 provides no clear-cut causality between innovations and growth. The existence of leads or lags for innovations is doubtful, and hidden periodicities are also possible. Therefore, such a descriptive approach to investigate causality is rather weak and probably misleading.

Figure 3.1 Patent Applications, Patents Issued, Investment and Value-Added.



Two major hypotheses will be tested in the following section. First is the traditional Schumpeterian hypothesis, that fluctuations in the number of innovations cause fluctuations in growth, versus the Schmookler hypothesis, that fluctuations in the number of innovations are rather being caused by fluctuations in growth. Second is the Mensch (1979) hypothesis – which is also Schumpeterian in spirit – that innovations occur in clusters, versus the van Duijn hypothesis that innovations occur randomly.

3.4 Causality between Innovation and Growth: the case of Sweden

3.4.1 Introduction

The problem of causality with regard to economic phenomena has always existed. The differences between functional (well known as “black boxes”) and causal models in macroeconomies and business cycles were initially illuminated by Åkerman (1936, 1960). According to him, functional dependence, expressed through “descriptive” or “calculation” models, does not imply causality. The major advantage of causality analysis over functional dependence models lies in the fact that the relationships between variables are not only speculated or based upon a priori theoretical reasoning, but are also given a causal meaning with certain probabilities. Åkerman states that:

“causal analysis explains the actual, total processes by a scrutiny of the motives, perspectives, and actions of the essential groups and the result of these driving forces as they appear in the variations of the time-series”.¹

Åkerman also argues that the contribution of economists (including both mathematical economists and economic historians) to the problem of causality was rather poor. He states:

“the origin of change in theoretical models and in reality, the relation between interdependence and causation, remained a black space on the map”.²

The departure from a purely theoretical argument to a statistical model explaining causality began in the 1960s with a pioneer work by Wold (1960). Granger (1969), Akaike (1969) and Sims (1972) have also contributed greatly since they constructed simple models and provided useful propositions and tests in order to examine the causal mechanism between two variables. Below, the Schumpeterian hypothesis will be tested by using Granger’s definition of causality together with Akaike’s final prediction error (FPE) criterion.³

¹ Åkerman, J., *Theory of Industrialism* (1960), p. 273.

² Op. cit. p. 285.

³ A similar procedure was undertaken by Hsiao, C., “Autoregressive Modelling and Money-Income Causality Detection”, (1981).

To my knowledge, there has been no work which investigates the exogeneity or endogeneity of innovations. All studies reviewed in the first chapter are based on either simple correlation coefficients or on simple regressions with ad hoc time lags. Schankerman (1984), expressed his wish to see empirical studies on the cross spectrum between the rate of patenting and the rate of growth of aggregate output.

We will now briefly review two of the approaches suggested to investigate causality.

3.4.2 The Granger approach

This approach is based on the simple idea that if there is a causal relation, then one ought to be able to observe a statistically lagged dependence.

Let us assume two bivariate stochastic processes

$$p_t = \psi_{11}(L)p_t + \psi_{12}(L)y_t + v_t \quad (1)$$

$$y_t = \psi_{21}(L)p_t + \psi_{22}(L)y_t + u_t \quad (2)$$

where: P_t denotes patents (applications and/or issued), and y_t denotes domestic investment or value-added in manufacturing in real prices.

L is the lag operator $Lw_t = w_{t-1}$, and

$$\psi_{ij}(L) = \sum_{k=1}^{m_{ij}} \psi_{ijk} L^k.$$

It is assumed that both v_t and u_t are white noise processes¹ so that least square estimates will be consistent and asymptotically normally distributed (Hsiao, 1981).

Granger (1969), Sims (1972) and Akaike (1969) have shown that the direction of causality can be examined by looking at the $\psi_{12}(L)$ and $\psi_{21}(L)$, or by comparing the mean square linear prediction errors of the autoregressive forms with the form which includes past foreign variables. In our bivariate system the following cases are possible:

¹ A white noise process is simply defined as:

$$E \begin{bmatrix} v_t \\ u_t \end{bmatrix} = 0, \text{ and}$$

$$E \begin{bmatrix} v_t \\ u_t \end{bmatrix} \begin{bmatrix} v_s & u_s \end{bmatrix} = \begin{matrix} \lambda, & \text{for } t = s \\ 0, & \text{for } t \neq s \end{matrix}$$

- (a) y_t causes p_t ($y_t \rightarrow p_t$), if $\psi_{12}(L) \neq 0$
- (b) y_t does not cause p_t ($y_t \nrightarrow p_t$), if $\psi_{12}(L) = 0$
- (c) p_t causes y_t ($p_t \rightarrow y_t$), if $\psi_{21}(L) \neq 0$
- (d) p_t does not cause y_t ($p_t \nrightarrow y_t$), if $\psi_{21}(L) = 0$.

Furthermore, two additional cases are worth mentioning.

- (e) *Feedback*: ($y_t \longleftrightarrow p_t$). This occurs when (a) and (c) are accepted simultaneously.
- (f) *Independence*: ($y_t \nleftrightarrow p_t$). This occurs when (b) and (d) are accepted simultaneously.

In the case of causality or feedback, not only own past values help to predict future values, but past values of a foreign (the causal) variable as well. These models are called interdependent autoregressive models. On the contrary, in the case of independence, only own past values are used to predict future values. These models are called autoregressive models (AR). To test if there is a causality running from y_t to p_t , the following model is used:

$$p_t = a_{10} + \sum_{j=1}^m a_{1j}p_{t-j} + u_{1t} \quad (3)$$

$$p_t = a_{20} + \sum_{j=1}^m a_{2j}p_{t-j} + \sum_{i=1}^n b_{21}y_{t-i} + u_{2t} \quad (4)$$

The causality runs from y_t to p_t , if the b_{21s} in equation (4) are statistically significant from zero.

The hypothesis to be tested is:

$$H_0: b_{21} = b_{22} = \dots = b_{2n} = 0$$

The value of the F-statistic is defined as:

$$F^* = \frac{\frac{SSE_3 - SSE_4}{n}}{\frac{SSE_4}{T-m-n-1}} \quad (5)$$

where: SSE_3 , SSE_4 are sum squared errors for equation (3) and equation (4) and T is the number of observations.

Thus, if F^* (which is distributed with $(n, T-m-n-1)$ degrees of freedom) is greater than the F_{f_1, v_1, v_2} (f_1 is the significance level and v_1, v_2 are the degrees of freedom), H_0 is rejected. Consequently, y_t does cause p_t , that is the non-causality from y_t to p_t is rejected. On the other hand, non-rejection of H_0 would imply that causality is not established. It should be pointed out here

that since relations between parameters are not accounted for in the set-up of F-tests, nothing can be said about the signs or values of the parameter of the equation.

Although Granger's approach is a useful method to analyze the presence or absence of causality between two time series, it is a rather simplistic and weak test. Åkerman (1960), for instance, does not classify such dynamic models (based on difference equations) as causality models. To quote from Åkerman:

“the difference equations of the deductive model sequences express a ‘causal’ connection between data in one year in e. g. the preceding year, but the ‘cause’ is given in the assumptions of the first ‘period’: there is no causality in the real sense. In causal analysis causality, the detection of driving forces, of dominating groups with leading perspectives and norms, is the main object of the investigation.”¹

Cooley and Le Roy (1985), have also criticized the Granger causality as being a rather weak test. In order to illustrate this they consider the following model:

$$m_t = \theta y_t + b_{11}m_{t-1} + b_{12}y_{t-1} + \epsilon_{1t} \quad (1)'$$

$$y_t = \gamma m_t + b_{21}m_{t-1} + b_{22}y_{t-1} + \epsilon_{2t} \quad (2)'$$

They interpret Granger's exogeneity test by taking into consideration not only b_{12} (respectively b_{22}) but θ (respectively γ) as well. Thus, according to them, m is “strictly exogenous” for y if $\theta = b_{12} = 0$.

Expressing that system in its reduced form yields:

$$m_t = \pi_{11}m_{t-1} + \pi_{12}y_{t-1} + u_{mt} \quad (1)''$$

$$y_t = \pi_{21}m_{t-1} + \pi_{22}y_{t-1} + u_{yt} \quad (2)''$$

In this case again, y fails to Granger cause m if

$$\pi_{12} = 0 \quad \text{where:} \quad \pi_{12} = \frac{\theta b_{22} + b_{12}}{1 - \theta \gamma}$$

Consequently, they come to the conclusion that: “Strict exogeneity does indeed imply Granger non-causality, so that failure of a Granger or Sims test is evidence against strict exogeneity, subject to the usual significance criteria. But the converse is not true: acceptance of Granger non-causality

¹ Åkerman, J., *Theory of Industrialism* (1960), p. 275.

does not imply (although it is consistent with) strict exogeneity: $\pi_{12} = 0$ implies $b\theta_{22} + b_{12} = 0$, not $\theta = b_{12} = 0$.¹

This critique, however, is not entirely clear because it depends on the way one interprets the Granger causality. Cooley and LeRoy assume that θ (respectively γ) must be included in the specified equation. Obviously, if θ (γ) are not included in equations, π_{12} will be just equal to b_{12} ($\pi_{21} = b_{21}$). At this point it is worth mentioning that Granger's definition of causality (quoted also in Cooley and LeRoy on page 286) is: "The series y_t fails to cause m_t if, in a regression of m on lagged m and lagged y , the latter takes on a zero coefficient." Thus, it would appear that Granger's test by definition does not apply to the kind of simultaneous relationship discussed by Cooley and LeRoy.

Two more comments should be made regarding the Granger test. First, since these "trial and error" tests are time consuming, one might not continue to search for the optimal time lag (however one chooses to define this) if the first two to three lags yield definitive results. The true optimal lag and causality might exist in a lag of a higher order. Second, the conventional choice of 5% or 1% significance level, with which the Granger approach is tested, is ad hoc. It would be desirable to find an explicitly optimal criterion to free us from the ambiguities inherent in the use of conventional procedures. Such a criterion need not be based on the F-statistic.

3.4.3 Akaike's approach

Akaike (1969) has provided us with such a criterion in order to determine not only the dependency which might exist between two variables, but the optimum order of lags as well. This is the final predicted error (FPE) criterion which is defined as the asymptotic mean square prediction error. For instance, the FPE for equation (1) is defined as:

$$FPE_p(m,n) = \left(\frac{T+m+n+1}{T-m-n-1} \right) \cdot \sum_{t=1}^T (p_t - \hat{p}_t)^2 / T \quad (6)$$

The first term of the product on the right hand side of equation (6) is a measure of estimation error while the second term represents a measure of modelling error. $\hat{p}_t$ is the predictor of p_t .

The philosophy of this criterion lies in its unbiasedness, since the bias from choosing a too small lag order is balanced against the increased

¹ Cooley, T. F., and S. F. LeRoy, "Atheoretical Macroeconometrics: A critique" (1985), p. 298.

variance from a higher lag order specification. Therefore, we do not need to investigate a high number of lag order to reach our conclusions.

To determine the causal direction and the number of lags which should be used in equation (1) or (2) one has to estimate the FPEs of all the possible combinations of lags and choose the smallest.

In order to limit the number of all these combinations of lags, the following procedure is suggested by Hsiao (1981).

First, we treat p as a one-dimensional autoregressive process by taking an order of lags varying from l to m and estimating all the respective FPEs. We choose the order which yields the smallest FPE, say q . That is:

$$p_t = \psi_{11}^m(L)p_t + \varepsilon_t \quad (7)$$

with $FPE_p(q,0)$.

Second, we treat p as a controlled variable with the order of $\psi_{11}(L)$ fixed at q . We then treat y as a manipulated variable. Let r be the order for the lag operator $\psi_{12}(L)$ which yields the smallest FPE. This is the occasional optimum. That is:

$$p_t = \psi_{11}^q(L)p_t + \psi_{12}^r(L)y_t + v_t \quad (8)$$

with: $FPE_p(q,0)$.

Third,¹ after we have estimated the order of the manipulated variable, we fix it to be equal to r and go back to the lag operator ψ_{11} , and let it vary from 0 to q . We compute the corresponding FPEs and choose the order of ψ_{11} that yields the smallest FPE, say s . This is the optimal AR (s,r) process: That is:

$$p_t = \psi_{11}^s(L)p_t + \psi_{12}^r(L)y_t + v_t \quad (9)$$

with: $FPE_p(s,r)$.

By comparing the FPEs of the first and third step, we decide upon the causality direction and its optimal lag order. That is:

(i) If $FPE_p(q,0) > FPE_p(s,r) \Rightarrow y \rightarrow p$

(ii) If $FPE_p(q,0) < FPE_p(s,r) \Rightarrow y \nrightarrow p$

¹ This step has not been taken by Hsiao because he considers it to be of minor significance. However, as will be shown later, this step appears to be necessary since the $FPE_p(s,r)$ can be smaller than the $FPE_p(q,r)$. To put it differently, when lagged values of y are also included, the true order of the autoregressive model might be lower. Obviously, if the order of lag operator ψ_{11} is one, there is no need to consider the third step, since it degenerates to the second step.

If case (i) is accepted, the general form (1) is specified according to the equation (9), which is an AR (s,r) process, while if case (ii) is accepted, the general form (1) is specified according to the equation (7), which is an AR (q,0) process.

Finally, a similar approach is undertaken for equation (2) to find out if the reverse causality yields equal FPEs (the case of feedback) or different FPEs (superior or inferior causal mechanism).

3.4.4 Stationary versus non-stationary series

It was assumed earlier that v_t and u_t in equations (1) and (2) must be white noise processes so that least square estimates will be consistent and asymptotically normally distributed. However, initial economic time series data are seldom stationary but are usually strongly affected by time (non-stationary). The common rule is to remove the trend by transforming the initial data. This form of transformation is called “pre-whitening” or “pre-filtering” and is obviously very cumbersome work. The difficulty stems from the fact that there are no general rules regarding the most appropriate “filter” to be used. The following filters have been suggested by some researchers: first differences of the original data, first differences of the logarithms of the original series, filter of the form $1 - 1.5L + .562L^2$, filters based on trigonometric forms, and finally filters based on more or less sophisticated functional forms. There are, however, no ideal filters.

For instance, a “strong” filter does clear and isolate the time series from any time effects but it always affects its shape and especially the location of its cyclical peaks or troughs. On the contrary, a “weak” filter does not affect the spectrum of the time series but usually leaves some time effects unchanged. For instance, in the work presented below, strong filters (first differences or first logarithmic differences, Figures 3.2 and 3.3) did abolish all time effects, and similarly affected the location of the peaks and troughs. First differences (Figure 3.2) yield a local peak in patents issued in 1920 which is higher than the local peak in 1982. This is because patents issued increased by 615 patents between 1919–1920 while between 1981–1982 the increase was 310 patents. However, when we look at Figure 3.1 we observe that this peak is just an upward point much lower than the local low point in 1981. First logarithmic differences (Figure 3.3) order the 1920 point as a global peak, because patents issued increased by 32 percent between 1919 and 1920. Accordingly, the maximum point in 1970 (13 690 issued patents) becomes one of the lowest peak points.

Figure 3.2 Patents Issued and Value-Added.
(First Differences.)

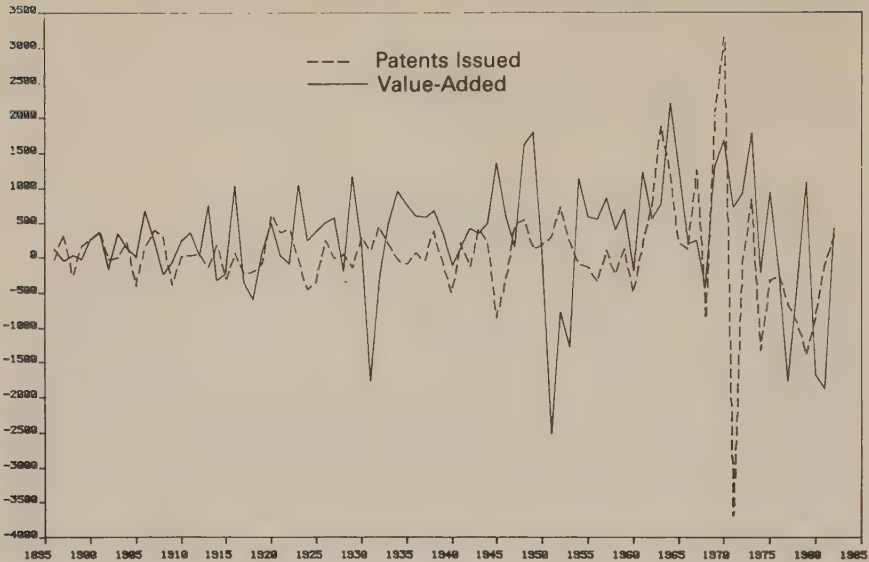
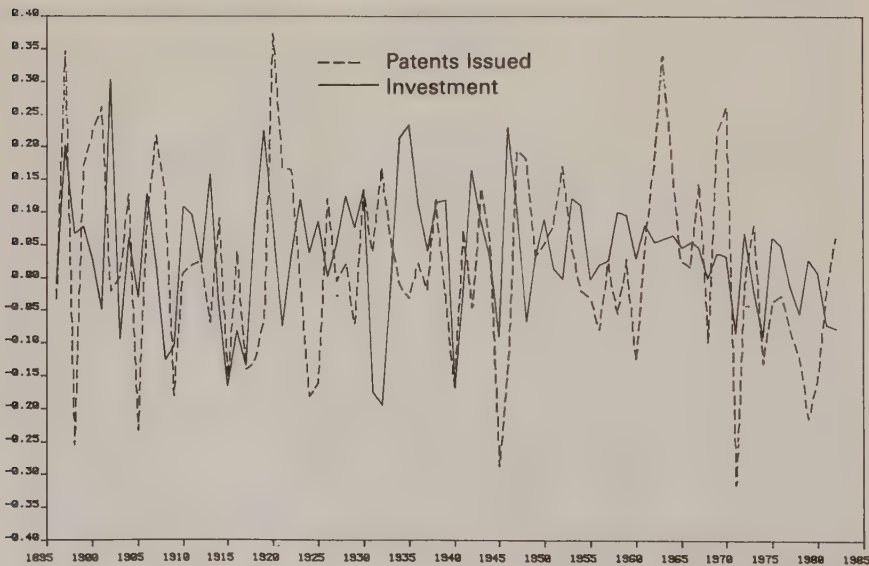


Figure 3.3 Investment and Patents Issued.
(First Logarithmic Differences.)



When one is interested in causality between variables and not only in finding hidden peaks and periods of a single time series, the problem of pre-filtering becomes even more complicated. If we are fortunate, both time series may be pre-filtered with the same filter and consequently can be compared. However, the probability of this is very low since different time series require different types of filters in order to become stationary. This leads us to misleading results (Plosser-Schwert, 1977).

All these problems convinced Geweke, Meese and Dent (1983) that tests which require pre-filtering are essentially useless for empirical work, thus they recommended a non-prefiltering procedure. To put it differently, although time or trend effects influence the consistency of our estimates it is impossible or unwise to eliminate these effects. The sharp decline in patents issued between 1970–1981 and the weak decline in patent applications between 1950–1981 is also an additional reason that pre-filtering is not necessarily required. The fact that patenting is positively related to time should not be interpreted to mean that the former is generated by the latter. Such a positive relationship might be a spurious one.

In this study, however, Akaike's causality test has been applied both to the initial (non-stationary) time series and to the prefiltered (stationary) ones. The patent applications (PA) series which is not as strongly related to time as patents issued (PI) series has been pre-filtered by taking first linear and logarithmic differences and then regressing that against time. The time coefficient then became insignificant. Value-added (V) became stationary by taking first differences and investment (I) by taking first logarithmic differences. Their stationarity is shown in Figures 3.2 and 3.3.

3.4.5 Estimates

The FPEs resulting from the treatment of each variable as a one dimensional autoregressive process are listed in Tables 3.1 and 3.3.

The smallest FPEs are enclosed in a frame. Tables 3.2 and 3.4 show the optimum lags of the manipulated variable and the FPEs of the controlled variable. These variables are controlled in the sense that their lag structure is fixed at the optimum lag determined in Tables 3.1 and 3.3. The optimum lag of controlled variables is given in parentheses.

Table 3.1: The FPE of fitting a one-dimensional autoregressive process for PA, I, and V. (Linear fits without filtering.)

The order of lags	PA $\times 10^5$	I $\times 10^5$	V $\times 10^5$
1	.7984	.2492	6.836
2	.8080	.2533	6.541
3	.8337	.2553	6.610
4	.8601	.2133	6.683
5	.8589	.2121	6.950
6	.8914	.2124	7.109
7	.9042	.2149	7.380
8	.9329	.2152	7.608
9	.9695	.2178	7.851
10	.9980	.2194	7.793

Table 3.2: The optimum lags of the manipulated variable and the FPE of the controlled variable.

Controlled variable	Manipulated variable	The optimum lag of manipulated variable	FPE $\times 10^5$
PA(1)	I	1	.8155
I(5)*	PA	1	.2057
V(2)	PA	2	6.453
PA(1)	V	1	8.159

Table 3.3: The FPE of fitting a one-dimensional autoregressive process for PI, V and I (after filtering)¹

The order of lags	DPI $\times 10^6$	DV $\times 10^6$	LDPI $\times 10$	LDI $\times 10$
1	.5921	.6397	.2163	.1938
2	.5934	.6432	.2074	.1976
3	.5410	.6531	.1987	.2019
4	.5527	.6702	.1986	.2088
5	.5762	.6918	.2022	.2106
6	.5792	.7188	.1980	.2120
7	.5987	.7391	.2051	.2127
8	.6117	.7597	.2116	.2152
9	.6009	.7631	.2147	.2174
10	.6066	.7871	.2196	.2182

¹ DPI and DV denote first differences of patents issued and value – added in a linear form, while LPDI and LDI denote first differences of patents issued and investment in a log-linear form.

Table 3.4: The optimum lags of the manipulated variable and the FPE of the controlled variable

Controlled variable	Manipulated variable	The optimum lag of manipulated variable	FPE
DPI(3)	DV	1	.5451 $\times 10^6$
DV(1)	DPI	6	.6131 $\times 10^6$
LDPI(6)*	LDI	3	.1952 $\times 10$
LDI(1)	LDPI	1	.1921 $\times 10$

The general impression given by these tables is that irrespective of the procedure applied (stationary or non-stationary time series) and the measure of variables, there are no variations in the causality. Thus, while the Schumpeterian causal mechanism was never rejected, the Schmookler causal mechanism was rejected in some cases.

More specifically, when the time series are non-stationary and the fitting processes are linear, the Schumpeterian hypothesis that past patent applications (PA) have caused domestic investment (I) and value-added (V) in manufacturing is not rejected since FPEs of PA on I and V are smaller (.2057 < .2121 and 6.453 < 6.541). On the other hand, the Schmookler hypothesis that past value-added and past investment have caused patent applications is rejected since FPEs of I and V on PA are larger (.8155 > .7984 and 8.159 > .7984). Thus, the respective optimal AR processes for these non-stationary time-series were:

(a) *Value-Added*: AR (2,2), that is:

$$V_t = a + b_1V_{t-1} + b_2V_{t-2} + \gamma_1PA_{t-1} + \gamma_2PA_{t-2} \quad F(2,86) = 2.66$$

(b) *Investment*:¹ AR (4,1), that is:

$$I_t = a + b_1I_{t-1} + b_2I_{t-2} + b_3I_{t-3} + b_4I_{t-4} + \gamma_1PA_{t-1} \quad F(1,84) = 5.18$$

(c) *Patent Applications*: AR(1,0), that is:

$$PA_t = 132.5 + .9705PA_{t-1}$$

¹ It should be mentioned here that the use of the third step of Akaike's test has changed the optimal lag of investments from 5 (see Table 3.2) to 4 years.

Second, when the time series have become stationary, the Schumpeterian hypothesis that past patents issued (PI) have caused value-added (V) is not rejected, since $.6131 < .6397$, while the reverse hypothesis is rejected since $.5451 > .5410$. When the causality between patents issued and investment was investigated, we could not reject a two-way mechanism (feedback).

The respective optimal AR processes for these stationary time-series were:

(a) *Value-Added*: AR (1,6), that is:

$$DV_t = a + b_1 DV_{t-1} + \gamma_1 DPI_{t-1} + \gamma_2 DPI_{t-2} + \gamma_3 DPI_{t-3} + \gamma_4 DPI_{t-4} + \gamma_5 DPI_{t-5} + \gamma_6 DPI_{t-6} \quad F(6,81) = 3.85$$

(b) *Patents Issued*:¹ AR (2,3), that is;

$$LDPI_t = a + b_1 LDPI_{t-1} + b_2 LDPI_{t-2} + \gamma_1 LDI_{t-1} + \gamma_2 LDI_{t-2} + \gamma_3 LDI_{t-3} \quad F(3,84) = 4.37$$

(c) *Investment*: AR (1,1), that is;

$$LDI_t = a + b_1 LDI_{t-1} + \gamma_1 LDPI_{t-1} \quad F(1,86) = 2.82$$

Although neither of these two measures – patent applications and patents issued – reject the Schumpeterian causal mechanism, the use of patent applications yields stronger Schumpeterian results than the use of patents issued. That is, while in the case of patent applications the possibility of the Schmookler causal mechanism simultaneously is very low, in the case of patents issued this possibility is not excluded when patents issued is related to investment.

¹ The use of the third step of Akaike's test has changed the optimal lag of patents issued from 6 (see Table 3.4) to 2 years.

3.5 Major Innovations

3.5.1 Fluctuations in Major Innovations

It was claimed in the previous chapter that major innovations are probably the least biased measure of innovations and that since major innovations are considered as a good proxy of the life cycle of innovations as well, their use is desirable. It was also argued that since major innovations are, by definition, economically successful, any investigation of their economic impact becomes trivial. Therefore, instead of testing such an unambiguous relationship, we will merely examine the exogeneity or endogeneity of major innovations from a different perspective. Similarly, we will discuss how major innovations can contribute to the steady process of expansion in Sweden and its major crises during the course of this century.

To test the exogeneity or endogeneity of major innovations in Sweden we will not apply any causality criterion such as that in the previous section. This is due to the small number of observations (major innovations), to the discontinuities which exist in major innovations, and to the variations in the shape and timing of their life cycles. Their endogeneity or exogeneity will be investigated instead by looking for any considerable time lag between major inventions and major innovations and the economic conditions which prevailed when these inventions became innovations. The argument runs as follows. If major innovations in Sweden have been fostered by “actual demand conditions” – as the “demand-pull” theory of innovations argues – one would expect considerable time lags between major inventions and major innovations. This is because a major invention invented in period t will have to wait until the demand conditions of period $t+i$ cause the commercial exploitation of that invention. The lack of time lags between major inventions and innovations is consistent with the “demand-pull” theory of innovations, only if the demand conditions which existed when major inventions were made were appropriate. Such a coincidence, however, seems very unlikely.

3.5.2 Exogeneity and Clustering of Major Innovations

Although clustering of minor innovations has been recognized by both Kuznets (1930) and Schumpeter (1935), the bunching of major innovations has been mainly considered by Mensch (1979). According to Mensch, major innovations do not only provide new frontiers to enrich the economy, they are also clustered around depression periods, because during these

periods stagnation is most pressing.¹

Mensch also separates the bunching of major inventions from the bunching of major innovations. The technological stalemates which have occurred in the past have not been used by a lack of major inventions. Mensch seems to accept the Schumpeterian explanation that entrepreneurial activities required to put these major inventions into practice are also distributed in bunches.

Freeman-Clark-Soete (1982) have supported some clustering on innovations, but these clusters are not necessarily related to depressions. A weak increase of major innovations appeared in the late 1930s and a decrease at the tail-end of long booms. Van Duijn (1983), on the other and, has rejected both Mensch's depression-trigger effect and clustering hypothesis. According to him, any observed differences in the number of major innovations are rather chance variations.

Obviously, the diversity of results is primarily due to two problems with the concept of innovations. First, although there are some innovations which are regarded as major by all researchers, there are also other innovations which are regarded differently by different researchers. Second, there is no unanimity regarding the introduction date of – at least some – major innovations.

Table 3.5 below summarizes all the major inventions and innovations in Sweden since its industrialization. The selection of them, as was pointed out in the previous chapter, was based on economic and technical criteria.

In most cases, agreement exists between an economist and a technician regarding the classification of an invention as major or not; take for instance, ball-bearings or the refrigerating system. These inventions are, without any doubt, considered as major from the economist's and the technician's point of view. The foundation and development of SKF and Electrolux justifies their great economic impact, while the hundreds of patents patented around these initial inventions illustrate the great technological opportunities of these inventions.²

There are, however, some innovations which an economist would consider as major, but not a technician and vice versa. These innovations were not included. For instance, there are some innovations which have occurred

¹ As was mentioned earlier Sweden, since its industrialization has experienced only a few deep depressions which were of a rather short duration. Therefore, the entire Mensch hypothesis cannot be examined. We should instead examine if the first half of this hypothesis – that major innovations come in clusters – is more relevant than van Duijn's hypothesis – that major innovations appear randomly in time.

² Vedin (1983) argues that by the 1980s about 1500 patents have been based on the 1923 "refrigerating system" patent. My own statistics show that by 1980 the SPRO has granted more than 500 patents to the SKF group which are related to the 1907 initial invention.

mainly in the service sector, such as financial innovations, computer programmes, new management techniques etc. IKEA, a well-known and successful innovation of organisation and distribution, exemplifies the kind of innovation which is excluded.

Finally, some other inventions have been excluded, despite the fact that technological opportunities and (probably) their economic effect have been rather high. This is because they have been mainly developed in public research institutes, thus their introduction date is rather unclear and their economic effect is hard to estimate. Among these we can mention the following: Electrolytic dissociations theory (1903) by S. Arrhenius (Nobel prize winner), method for construction and developing iron-sponge (1904) by M. Wiberg, synthetic rubber (1926) by T. Svedberg (Nobel prize winner), and methods for separation and analysis in biology (1948) by A. W. K. Tiselius (Nobel prize winner).

The degree of significance of the included innovations varies greatly from the most important ones (such as the desk telephone, the cream separator, the electrical motor, ball-bearings, the refrigerating system and more recently the AXE-system and SAAB-Turbo, to name a few of them) to the less important ones (such as watches, the adding machine and paraffin stove). The possibility of having missed some patented inventions must, however, be acknowledged.

Surprisingly enough, the time lag between major inventions and innovations in Sweden is, in general, negligible. Of the forty-nine major inventions since industrialization, only sixteen showed some delays. The time lag varied between one and eight years. Moreover, the five delays which have occurred in the exploitation of pharmaceutical inventions are probably due to the necessary formal controls undertaken by Swedish and/or foreign authorities. Therefore, we may argue that by identifying major Swedish inventions with major innovations we do not commit any significant bias.

It is also of interest to note that some of the most important of these major inventions became innovations during recession years!

Thus, the immediate identification of major inventions with major innovations, together with the fact that many major inventions in Sweden have become innovations when the aggregate demand of the economy was rather low seems to cast some doubt on the "demand-pull" theory of innovations.¹

¹ Obviously, it can not be denied that many of these major inventions – especially those invented during recent decades – have been the successful results of long run and expensive projects which cover boom and slack years as well. However, the true message of the "demand-pull" theory of innovations does not lie in the presence of demand during the "birth" of an invention, but during the development period of that invention, i. e. when invention becomes innovation. In the case of the AXE-system or SAAB-Turbo, for instance, these inventions were not delayed due to the recession period as the "demand-pull" theory of innovations argues, but became innovations almost immediately.

Table 3.5: Major Swedish and semi-Swedish* inventions and innovations over the period 1858–1978.

Year for a patent application	Invention	Inventor	Developer Firm	Year of development
1 1858	steel process*	H. Bessemer G. F. Göransson	Sandvikens Jernverk	1862
2 1864	dynamite	A. Nobel	Nitroglycerin	1864
3 1874	process for sulfate and cellulose	C. D. Ekman	Bergviks Trämassefabrik (SCA)	1874
4 1876	desk telephone	L. M. Ericsson	L. M. Ericsson	1876
5 1878	cream separator	G. de Laval	Alfa Laval	1878
6 1880	adding machine*	W. Odhner	Original-Odhner	1880
7 1882	electrical motor	J. Wenström	ASEA	1883
8 1883	steam turbine	G. de Laval	ASEA	1883
9 1885	craft paper process	A. Muntzing	Munksjö Mill	1885
10 1885	sulfate pulping process	C. Carlson	many	1885
11 1887	watches*	–	Facit-Halda	1887
12 1890	3-phase transfer of electric power	J. Wenström	ASEA	1891
13 1892	adjustable spanner	J. P. Johansson	Munktells mekaniska verkstad (Bahco)	1892
14 1893	chlorine-petrochlorine	O. Carlson	Månsbrofabrikerna (Kema Nobel)	1893
15 1896	typewriter*	–	Facit-Halda	1896
16 1898	paraffin stove	F. W. Lindqvist	Primus	1898
17 1900	industrial welding electrode	O. Kjellberg	ESAB	1900
18 1904	process for converting fluid milk into powder	M. Ekenberg	many	1904
19 1904	accumulator	E. W. Jungner	Nife Jungner	1907
20 1904	acetylen-gas	G. Dalén	AGA	1909
21 1907	ball-bearings	S. G. Wingquist	SKF	1907
22 1907	progressive tolerance measure	C. E. Johansson	AB C. E. Johansson	1911
23 1909	electrical furnaces	–	Domnarverts Jernverk	1909
24 1918	spherical roller-bearings	N. A. Palmgren	SKF	1918
25 1918	conical roller-bearings	N. A. Palmgren	SKF	1918

Year for a patent applica- tion	Invention	Inventor	Developer Firm	Year of develop- ment
26 1922	oven	G. Dalén	AGA	1930
27 1923	refrigerating system	B. C. von Platen C. G. Munters	Electrolux	1930
28 1926	locomotive with geared turbines	B. Ljungström	Stal-Laval	1926
29 1931	roller-bearings in double rows	S. G. Wingquist	SKF	1931
30 1940	xylocain	N. Löfgren	ASTRA	1948
31 1946	HUMI-KOOL	C. G Munters	Incentive	1946
32 1948	6×6 camera system	V. Hasselblad	V. Hasselblad AB	1948
33 1950	Respirator	C. G. Engström	Enström Medical	1950
34 1950	Automatic sugar- spinner	—	Cardo	1950
35 1950	WKE-4 (steel- method)	—	Fagersta	1950
36 1951	Tetra Pak	R. Rausing E. Wallenberg	Tetra Pak	1954
37 1953	Coordination choice system	—	Ericsson	1953
38 1954	High energy transformer	—	ASEA	1954
39 1954	ASEA-SKF method	—	ASEA	1958
40 1954	Sephadex	—	Pharmacia	1961
41 1965	dialysis machine	H. Crafoord	Gambro	1967
42 1966	Bricanyl	—	Draco (Astra)	1968
43 1973	mechanical transference for robots	—	ASEA	1973
44 1973	Debrisan	—	Pharmacia	1975
45 1973	Signalsystem	—	Televerket	1973
46 1973	Automatic processing for ball-bearings	—	SKF	1973
47 1974	High temperature resistant steel	—	Avesta Jernverk	1974
48 1976	SAAB-TURBO	—	SAAB	1976
49 1976	AXE-system	—	Ericsson	1978

Sources: BRA BÖCKERS LEXIKON

MacQueen, D. H., and J. T. Wallmark (1983)

Patent, SPRO (annually)

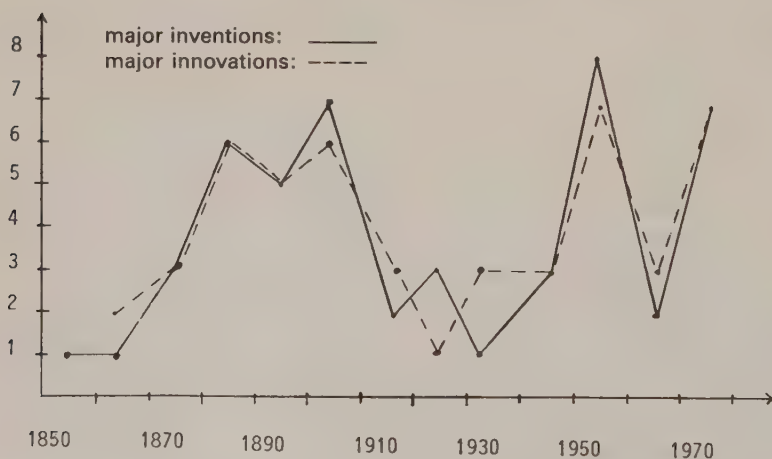
Companies' Annual Reports.

An explanation as to why there are no significant time lags between major inventions and innovations in Sweden, is that in this country inventive and entrepreneurial ability are often integrated within the same person. This obviously makes it easier to turn a major invention into innovation irrespective of the existing “actual demand conditions”. Among these great personalities we can mention A. Nobel, L. M. Ericsson, G. de Laval, O. Carlsson, J. P. Johansson, S. G. Wingqvist, C. E. Johansson, G. Dalén, V. Hasselblad, R. Rausing and H. Crafoord.

Turning to Mensch’s clustering hypothesis some weak support is provided. Figure 3.4 below depicts a clustering of major inventions and innovations which started with industrialization and ended by the end of the 1910s. The length of that cluster is, approximately, equal to one Kondratieff cycle. Between 1920 and the end of the 1940s there were not many major innovations. A weak and shorter clustering of major inventions and innovations seems to have appeared between the end of the 1940s and the end of the 1950s. Finally, some major innovations appeared during the 1970s.

Such a discontinuous time distribution of major innovations, however, causes some problems regarding the characteristics of Swedish economic growth. One, for instance, should expect – in a Schumperian view – that the Swedish economy would have been characterized by significant and long fluctuations in its economic growth and not by rather stable rate of growth.

Table 3.4: Clustering of major inventions and innovations in Sweden (by decades).



To explain the characteristics of Swedish economic growth, one is thus left to speculate. As far as the overall comparison of the clusters is concerned there is no doubt that almost all major inventions which took place between industrialization and the end of the 1910s were more significant than those which appeared during the last 30 to 40 years. There are, moreover, a few major innovations (such as the AXE-system, SAAB-Turbo, Robots, Tetra-Pak and Dialysis machine) whose diffusion paths¹ are expected to be quite long and steep, though not as long and steep as the diffusion paths of the desk telephone, the cream separator, the electrical motor, the steel process, and ball-bearings. For instance, SKF within 30 years from its foundation provided work for more than 10 000 Swedes which is twice as much as the employment generated by Tetra-Pak, Gambro and the Robotics division of ASEA together. Similarly, public telecommunications which accounted for more than half of Ericsson's turnover in the beginning of the 1970s (almost 4 000 million SEK in 1975 prices) accounted for less than thirty-five percent in 1983 (almost 3 600 millions SEK in 1975 prices) even including the successful AXE-system.

Also, a detailed investigation of the annual reports of many of the companies established during the first decades of industrialization reveals a common pattern. The equilibrium stages of almost all major innovations which appeared during the first clustering period seem to have been reached by the middle of the 1970s. Ericsson, Alfa-Laval and SCA registered maximum employment figures in 1975, ASEA in 1976, SKF in 1965, Kema Nobel, Nitro Nobel and AGA in 1978 and Sandvik in 1980. Similarly, by the middle of 1970s more than half of ASEA's, Alfa-Laval's, Ericsson's, Kema Nobel's and Nitro Nobel's turnover was generated outside their major innovation activities. Also SKF's production of ball – and roller-bearings reached its global peak in 1974 and thereafter declined. If the equilibrium stages of almost all these companies were reached by the middle of the 1970s, and the diffusion paths of most recent major innovations have not been that long and steep, this could help explain the modest rates of growth in the Swedish economy in the 1970s and early 1980s.

3.6 Conclusions

The purpose of this chapter was to test the Schumpeterian causal mechanism, discussed in the first chapter, between innovations and economic growth.

¹ Nabseth, L., *Innovationsspridning inom svensk industri* (1973), and Kling, D., *Spridning av ny teknik* (1979), have investigated the diffusion process in some industrial sectors in this country.

Obviously, testing the entire Schumpeterian theory of innovations and economic growth through business cycles is an extremely difficult task. As a consequence, only a small part of that theory was tested, i. e. if innovations in Sweden cause economic growth – as Schumpeter argued – or if they are induced by economic growth – as the “demand-pull” theory of innovations has advocated. Fortunately, the rather steady-state rates of growth in Sweden and the lack of marked business cycles, have facilitated the performance of tests.

The Granger-Akaike causality test, carried on in the first part of this chapter, did not reject the Schumpeterian hypothesis that innovations as measured by patents caused Swedish economic growth in terms of investment and value-added. Major innovations, discussed in the second part, showed some weak clustering or bunching of innovations which, however, have not generated similar patterns in economic growth. This might be due to the fact that these major innovations which took place during the first decades of industrialization, turned to have more significant economic effect than major innovations of the recent decades.

We may, therefore, argue that the high growth rates in Sweden during the 1950s and 1960s should not be seen only in the light of the upward trend of patent applications and approvals which occurred just a few years earlier. They should also be considered as due to the fact that the major innovations of the clustering period 1860–1920 seem to have reached the equilibrium stages during the 1950s and 1960s.

Similarly, the crisis of the 1970s might not be due to the oil crisis, the international depression, cost-push and demand-pull inflation, the explosion of the public sector etc., as is often claimed. Our approach provides an additional explanation.

The unfavourable development might also be due to: (a) The decline in the number of patent applications and approvals which started in the beginning of the 1970s. (b) The declining support provided by the old major inventions in the 1930s and 1940s and the less important ones in the 1950s and 1960s.

We may have underestimated the true number of major innovations in this country by concentrating only on patented innovations. The share of unpatented major innovations, such as financial innovations, innovations in computer programming, and innovations in management, organization and distribution might have increased. Coming decades will reveal if there have been such major innovations or not. One conclusion, based on the reasoning above, is that the next five years or so should show economic improvement if the volume of patents continues to increase, as it did during the period 1982–84.

Chapter 4

The Determinants of Inventions in Sweden

4.1 Introduction

After discussing the Schumpeterian mechanism of innovation and showing that such a mechanism appears to have been relevant in explaining Swedish economic growth, we will now attempt to identify and, hopefully, quantify the determinants of inventions.¹

If innovations in Sweden have been endogenously determined as the “demand-pull” school of innovations argues, there would be no need for a further investigation of its determinants. Innovations could be fostered by stimulating aggregate demand, that is by applying an expansive Keynesian economic policy. The rejection of the “demand-pull” hypothesis, however, casts some doubt on the idea that innovations can be promoted by applying such a policy. Consequently, one has to look for the determinants of inventions – if inventions can ever be endogenized – in some other parts of the system.

The first ideas concerning endogenous inventions were put forth by the supporters of the “supply-push” school. Schumpeter, for instance, when he discussed the “creative-destructive” mechanism stressed some socio-economic and psychological factors. Recently, Mensch argued that it is the lack of demand conditions which exist during recessions and depressions that stimulate major innovations. His theory, as was seen in the previous chapter, could not be supported by Swedish data.

Going back to Schumpeter, we find two independent but not contradictory hypotheses which deal with the determination of inventions: the role of individuals and the role of large firms and monopolistic market structures. Thus, the development of capitalism should be identified with the existence and the continuous supply of innovations brought about by great inventors and entrepreneurs during the first years of industrialization, and by large and monopolistic firms thereafter.

The purpose of this chapter is to examine to what extent these two Schumpeterian hypotheses are suitable to explain inventive activities undertaken in Sweden. The analysis consists of two parts; the first part will focus on the role of individuals, while in the second part the relationship between firm size, market structure and invention will be analyzed.

¹ Since it has been shown that innovations can, in general, be approximated by inventions (patents), these terms will be used interchangeably.

It should be mentioned at this point that neither the first nor the second hypothesis will be empirically analyzed over long periods of time. This is understandable, due to data limitations. The second hypothesis in particular – which requires effort to collect all relevant data – will be investigated only for a short time period. Thus, one should be very careful in drawing any policy implications or making forecasts regarding the impact of large firms and monopolistic market structure on innovations based on this data.

4.2 The Role of Individuals

The young Schumpeter, Schumpeter I, expounded his ideas about individuals in his *Theory of Economic Development* (1912). There he argues that the discontinuous flow of inventions (major and simple) is exogenous and independent of the size of firms and the structure of markets. The application of these inventions, however, if they prove to be major, might influence the existing market structures and also lead to a capitalist society. Thus, the driving forces in capitalist economies should be looked for in the group of entrepreneurs who realize the potential of these inventions and are willing to take the risk of developing and innovating.

Their role, however, is steadily declining mainly due to the growing hostility which individuals face in modern societies. Large organizations are expected to take over the role of individuals.

Sanders (1962) and Jewkes-Sawers- Stillerman (J-S-S, 1968) argued that since the beginning of this century inventive activity has shifted progressively from individual effort to more organized efforts, although individuals still hold a considerable percentage of “significant” inventions. For instance, J-S-S studied 61 significant inventions during the 20th century and found that 33 were the work of independent inventors.

In order to see if the Schumpeter I hypothesis has held true in Sweden, relevant data have been collected. First, we will examine the number and share of patents held by individuals for certain years and second, the share and the trend of major inventions.

4.2.1 Patents and Individuals

The statistics, as published by the S.P.R.O., are not particularly appropriate for studies of this type. For instance, patent applications are classified by nationality only and not by persons or by companies. Patents issued are even worse, because they are classified neither by nationality nor by persons or companies. Therefore, a detailed investigation (i.e. a year by year collection of patents) and a re-working of data was unavoidable.

Due to the time involved in collecting these data, the investigation was

limited to patents issued, covering selected years during the period 1950–1982. The volume of patent applications has also been collected for some years during that period, in order to obtain a better idea about the role of individuals in Sweden.

Needless to say, the period under consideration does not cover the first stages of industrialization in Sweden. Consequently, the Schumpeter I hypothesis will only be tested partially. Our data cover some sample years of the period 1950–1982. This period has been chosen in order to match the period under discussion in other sections of the thesis.

The procedure for separating individual patents from those of companies is as follows. In the appendix of the year book “Patent”, patents issued are summarized in alphabetical order. Both Swedish and foreign companies are easily identified. All the companies which appear with the Swedish “AB” (Ltd.) were considered as Swedish. On the other hand, the identification of individuals – that is independent inventors – was extremely time consuming, as double counting is prevalent in the appendix of that book. Patents issued are there registered under both the individual and the company, if the person in question is employed by the company or has sold the invention to the company. Therefore, before we identified a Swedish name as an independent inventor, the year book had to be investigated in detail.

The following rule has then been applied. All patents which have been issued to companies (as they are published in the appendix of the year book “Patent”) are regarded as patents issued to companies and not to individuals. In other words, in order for a patent issued to be registered to an individual, that individual must have patented the invention under his (her) name.

This rule does not necessarily imply a bias against individuals who are employed by a company. The employee is not forced to sell his inventions to the company before they are patented. He or she can patent the inventions under his or her name and as a consequence these patents should be considered as patents issued to individuals. Since 1949, a law has existed stating that the employee has, in theory, the right to his invention¹ (Neumeyer, 1977). But even prior to that period the same person could have been issued a patent in his or her name (as an individual) and another patent in the name of the company for which he worked. For instance, S. G. Wingquist, the founder of SKF, was issued patents both under his own name (as the individual S. G. Wingquist) and under the name of SKF.

¹ Obviously, that does not happen if he or she is employed to design or develop new products or processes.

In practice, the legal rights of the patenting individual might prove irrelevant. The worker or employee responsible for a specific invention might prefer to sell the invention to the company for which he (she) works before an application for a patent is made, so that the role of individuals might be underestimated. Their decision to sell the non-patented invention to the company can be due to the following reasons. First, individuals might not want to undertake the costs of possible litigation in defending their patent in court. Second, individuals might not be willing to wait for a final decision regarding the property of the patent. Third, individuals have neither the financial resources nor the ability to judge, in advance, the economic and technical potential of their invention.

Since these explanations seem quite plausible, we can never be sure of the true role of individuals. A great deal of our findings will depend on the degree to which these factors occur. Keeping this in mind, let us see what our collected data show regarding the role of individuals in Sweden.

The descriptive statistics which are presented in Table 4.1 do not seem to show any remarkable shifts in the inventive activities undertaken by individuals for these selected years. The following points should be made.

First, in Sweden, the percentage of patent applications applied for by individuals between 1950 and 1979–80 has remained roughly unchanged (about 40 percent). Lack of data for the entire period does not allow us to draw any statistically significant conclusions. However, these figures are higher than similar figures for the U. K. and U. S. A. According to Taylor-Silberston (1973), the corresponding shares of individuals for these countries were 25 and 30 percent respectively in the early 1960s.

Second, no decline in the share of patents issued to individuals is revealed from our selected years. Their share is approximated to fluctuate between 30 and 40 percent. In 1951 it was 29 percent, thirty years later it fell to 27 percent and in 1982 increased to 37 percent. It is interesting to add at this point that the share of patents issued to individuals, in relation to the entire number of patents issued by the S.P.R.O., has also been rather constant (between 7 and 11 percent).

Third, it is interesting to look at the degree of success of patent applications which were approved one and two years after the application was made. The degree of success should be regarded as a good indicator of the ability to invent or of the quality of inventions. A high (low) degree of success will therefore imply a high (low) ability to invent or reveal something about the quality of inventions. Although the findings reveal a lower success for individuals than for firms, the degree of success for individuals seems to have increased faster than for firms. For instance, only 13 percent of patent applications made by individuals in 1950 were approved in 1951. The corresponding percentage for companies was 19

Table 4.1: Swedish Patent Applications and Patents Issued.

	Patent Applications from Swedish Applicants			Patents Issued to Swedish Applicants		
	Individuals*	Companies*	Total**	Individuals' Percent	Individuals***	Companies*
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1950	2351	3944	6295	.37	759	1041
1951			5410		739	1091
1961			3804		711	1776
1967			5309		1129	2727
1970			4343		1849	2245
1971			4397		1319	1888
1976			4141		1293	1514
1979	1315	2801	4116	.32	1048	1394
1980	1785	2321	4106	.43	940	1321
1981			3914		963	1607
1982			4087		1010	

* Own measurement

** Year Books (SCB)

*** Own measurement for years 1951, 1961, and 1970. Evenson (1984) published total patents issued to nationals for years 1967, 1971, 1976 and 1980; the SPRO also published in its annual report (1983) total patents issued to nationals for years 1979-1982. Consequently, the patents issued to individuals for these years were simply calculated as the difference between column (7) and (6).

percent and the overall success (by both individuals and companies) was 17 percent.¹ In 1982, 597 patent approvals went to individuals out of the 1315 applied for in 1979 (45 percent). The corresponding approvals for companies was 43 percent and the overall approval rate was 39 percent.²

What do all these findings indicate in terms of support for the Schumpeter hypothesis? Obviously, the answer is not straightforward. It is quite risky to argue what might have happened during the first stages of Swedish industrialization based on some indications for selected years three quarters of a century later. First, we have no estimates for the entire period 1950–1982 which means that no backward extrapolation is possible. Second, the possibility of cycles in the share of patents held by individuals and firms prohibits us from such an extrapolation. Thus, what one may argue is that the Schumpeter I hypothesis seems not to have lost its relevance during the last 30 years. The contribution of independent inventors is still significant as far as patenting activities are concerned.

4.2.2 Major Inventions and Individuals

To substantiate our speculative conclusion about the significant role played by individuals, it is of interest to examine to what extent individuals have been responsible for the major inventions in Sweden. Fortunately, the statistics on major inventions collected cover not only the last thirty years but the entire period since industrialization. Thus, we can compare the role of individuals during the first stages of industrialization to that of recent years.

A quick glance at Table 3.5 in the previous chapter would show us that the role of individuals has been very important. To summarize this argument, the following points can be made.

First, out of 49 major inventions listed in Table 3.5 since 1864, 32 have been invented by individuals. This is a large share indeed, slightly greater than that found by Jewkes-Sawers-Stillerman (1960).

Second, out of 20 major inventions from the first decades of industrialization (1864–1907), individuals were responsible for 18. The name of the inventor is missing for the remaining 2 major inventions.

Third, almost all well-known inventions in Sweden have been invented by individuals: Dynamite (A. Nobel), the process for sulfate and cellulose (C. D. Ekman), the desk telephone (L. M. Ericsson), the cream separator

¹ The average processing time for patents granted in the early 1950s was approximately 1 year (own calculations).

² The SPRO estimates of the average processing time for patents granted during the last four years is approximately 3 years (Annual Report, 1983, SPRO).

(G. de Laval), the electrical motor (J. Wennström), the steam turbine (G. de Laval), the adjustable spanner (J. P. Johansson), acetylen-gas lighting (G. Dalén), ball-bearings (S. G. Wingquist) progressive tolerance measure (C. E. Johansson), refrigerating systems (B. C. von Platen – C. G. Munters), xylocain (N. Löfgren), 6×6 camera system (V. Hasselblad), Tetra Pak (R. Rausing – E. Wallenberg), dialysis machine (H. Crafoord).

Fourth, in many cases, the exploitation of these inventions by the inventor himself led to the establishment and growth of a company. That the founder of a company or the entrepreneur is often identical to the inventor is a fact which might have surprised Schumpeter¹ if he had investigated Swedish inventions/innovations. A. Nobel, C. D. Ekman, L. M. Ericsson, G. de Laval, W. Odhner, G. Dalén, S. G. Wingquist, C. E. Johansson, C. G. Munters, V. Hasselblad, R. Rausing and H. Crafoord were not only great inventors, they were successful innovators and entrepreneurs as well.²

Finally, since the 1950s, the role of individuals has declined drastically and large, well-established companies tend to take over.

This fact, seems to cast some doubt on our previous finding regarding the role of individuals in patenting activities. Thus, we are left with two conclusions – not necessarily contradictory – as far as the role of individuals is concerned. While the Schumpeter I hypothesis was more relevant to the first stages of industrialization in Sweden and rather irrelevant recently (in terms of major inventions) that hypothesis still seems to be valid in the present when all patent applications and patents issued are used as a measure.

If the era of the individual inventor has passed – as far as major inventions are concerned – what could be the reasons for this?

Various kinds of answers have been proposed, all of which are, to some extent, relevant. It is usually argued that today's inventions are technically complex and differ greatly from the inventions made some decades ago. The majority of inventions then consisted of simple mechanical constructions, in contradiction to today's inventions – especially in chemistry,

¹ Schumpeter usually separated the persons who carry out the invention from those involved in the innovative activities. The possibility that the two activities could be undertaken by the same person is not eliminated but "is merely a change of coincidence which does not affect the validity of the distinction", *Business Cycles*, vol. I, op. cit., 1939 (p. 86).

² While this thesis was in its final stages a new major invention made by an individual was announced: Stig Lundbäck's patent for an "artificial heart", an invention which is expected to bring about a new era in medicine. Astra, the largest pharmaceutical group in Sweden, has already founded a new company (ASTRA TECH) to improve that invention. Its executive director will be Stig Lundbäck himself. Similarly, the "cash-adaptor" invention, invented by Leif Lundblad in the middle of the 1970s and developed by his own company (Inter-Innovation), started to bring about considerable profits.

medicine, pharmacology, electronics, military defense, nuclear energy etc. – which require well-organized research laboratories or institutions.

It is also argued that the individual inventor is more easily absorbed by such institutions or organizations today and therefore operates as a part of a team and not freely or independently. The absorption of individuals by institutions has been facilitated by the following phenomena:

- (a) Individuals do not possess the financial means to test their ideas.
- (b) They usually lack contacts with other inventors, because they work in an isolated environment not conducive to research.
- (c) The creation of new institutions offers not only tempting careers, but also relevant information, advice and tools.

Finally, one should take into account inventors' role in society. According to Jewkes-Sawers-Stillerman (1960), inventors have been consistently treated "scurvily", "clumsily" and "harshly" by society. This treatment has been considered, "one of the strongest traditions in the history of this subject".¹ They also argue that:

"if it is true that the giants in the history of invention have been baffled by the perversity of men in rejecting what was designed only for their good, it must be much truer of a thousand smaller men with less to offer and less determined in their assaults on the barriers of custom and indifference".²

Schumpeter also considered that factor as being essential for the future of capitalism. A very pessimistic Schumpeter wrote in 1950, regarding the decomposition of capitalism:

"Faced by the increasing hostility of the environment and by the legislative, administrative and judicial practice born of that hostility, entrepreneurs and capitalists – in fact the whole stratum that accepts the bourgeois scheme of life – will eventually cease to function. Their standard aims are rapidly becoming unattainable, their efforts futile."³

Despite the fact that Schumpeter was talking about entrepreneurs and capitalists, that statement could include inventors as well. In Sweden, as was noted earlier, some of the greatest inventors had both entrepreneurial and capitalistic abilities. Thus, the increasing hostility of the environment would consequently cause a retardation of inventive activity.

Vedin (1982)⁴ has also stressed that factor in the case of Sweden. Accord-

¹ Jewkes, J., Sawers, D., Stillerman, R., *The Sources of Invention* (1960) p. 110.

² Op. cit. p. 113.

³ Schumpeter, J. A., *Can Capitalism Survive?* (1950), p. 96.

⁴ Vedin, B.-A., *Innovationsklimat i Sverige*, SNS, (1982), p. 168.

ing to him, the innovative climate in this country has deteriorated considerably since the middle of the 1950s, and inventors have felt a bitter disappointment. Inventors are no longer regarded as heroes and the concept of invention is valued quite low these days.

However, the innovative climate was hardly better previously¹, and remains at least equally bad in other countries. But this does not mean that climate can be regarded as a less serious or irrelevant problem. One cannot expect inventors to constantly improve the conditions of life when society consistently treats them unfairly. If creativity cannot be trained it should be, at least, let free.

Before we turn to an analysis of the size of firms, the structure of markets, and their influence on inventive activities in Sweden, we should mention the following point. It is very difficult, if at all possible, to judge if society gains from organized research activity or organized inventive ability. Similarly, it is difficult to argue that the declining role of individuals in inventive activity has been consciously encouraged or forced by society.

4.3 Firm Size, Market Structure and Inventions

4.3.1 Introduction

During recent decades, there have been numerous studies (mainly empirical), which test the Schumpeter II hypothesis: that is, if large firms and monopolistic market structures provide better conditions for inventions than smaller and more competitive firms. Although these studies do not provide any clear-cut evidence regarding the optimum firm size and the most appropriate structure of the market needed to maximize the rate of inventive activities, there is a tendency to favour medium-sized firms operating in weakly concentrated markets.

On the theoretical level, the disagreement among researchers is much greater. A large menu of theories has been supplied based on a variety of arguments. The extreme positions held by Schumpeter (1943) and Arrow (1962), favoring monopolies and pure competition respectively, have been moderated by the so-called "Neo-Schumpeterians" (Nelson (1959), Scherer (1967), Phillips (1971) and Kamien-Schwartz (1976)), among others. According to them the existing rivalry in oligopolistic markets, the

¹ Hallvarsson (1980), refers to three characteristic cases in which three of Sweden's greatest inventors are involved. L. M. Ericsson had great difficulties to borrow only 1600 SEK (!) to finance the foundation of his company; G. de Laval also had many problems in persuading his cousin to finance the 3000 SEK (!) for commercial exploitation of his invention; finally, C. E. Johansson fruitlessly attempted to persuade financiers about the opportunities of his progressive tolerance measure. It was Henry Ford, who had foreseen the tremendous contribution that invention could make to the motor industry, and later invited him to USA.

higher degree of diversification, and of technological opportunity are more significant than the size of the firm and the concentration of the market in which firms operate.

In Sweden, studies of this type are very rare: there are only two studies¹, Johannisson – Lindström (1971) and Anderson – Ohlsson (1983). In the following sections we will address the question if and to what extent the Schumpeter II model is appropriate for explaining inventive activities of the 1970s.

As was mentioned earlier, the rate of inventions in Sweden measured in terms of patents issued and applications declined sharply during the 1970s. This trend, which has been found in other countries as well (Evenson 1984), seems to be correlated with the increase in concentration in the Swedish manufacturing sector which occurred between 1967–1970², and has continued since then. The question which arises is if the increase in concentration is the cause of that decline (in which case the Schumpeter II hypothesis becomes invalid) or not.

This question is the focus of the following part, which consists of five sections. In the first section, the main arguments are presented, for and against large firms and monopolistic market structures. Section two is devoted to the previous empirical results in this area, by extending the Kamien Schwarz (1975) review to recent years. In section three we discuss measurement problems and the data set. The hypothesis to be tested and the regression results are presented in section four. Finally, some concluding points are presented in the fifth section.

4.3.2 The Role of Firm Size and the Market Structure

Researchers in this area do not, in general, differentiate between the firm size and market structure concepts. To simplify their analysis, they identify large firms with monopolistic market structures, medium size firms with oligopolistic market structures and small firms with competitive market structures. Accordingly, the arguments proposed for or against a particular size of firm fit very often into the respective market structure.

¹ There is also another study (O. Granstrand, *Technology Management and Markets*, 1979), which stresses mostly the organizational and managerial skills as being determinants of innovations in Sweden.

² According to SPK (the State Board for Prices and Cartels), the concentration in Swedish manufacturing increased between 1967 and 1970 from 68 to 72 percent. See SPK (register) *Marknad och fusioner 1963–1970*, Lund (1971).

This rough simplification does not encompass the well-accepted definition of the market or industry, which must take into account the following points:¹

- I. The degree of concentration (number and size of firms)
- II. The degree of homogeneity of products.
- III. The convenience to enter into and exit from the market.
- IV. The degree of interdependence in decision making (rivalry).

It is not clear how these four characteristics are related to firm size. For instance, the degree of concentration should not only be considered alone as an independent factor of market structure, but also simultaneously with firm size in order to determine the level of inventive activity. It is not certain that a large firm will necessarily operate in a highly concentrated market. A large firm is, in general, highly diversified and operates in many markets simultaneously. On the contrary, a medium size firm which is less diversified may well be one of the four largest firms which dominate a particular market (as defined by the concentration ratio). It must also be mentioned that a small firm which happens to operate in a highly concentrated market might behave differently than a firm of the same size which operates in a low concentrated market. Evidence provided by our sample indeed supports the postulate that there is no strong relationship between size (measured by employment or sales) and the concentration index (see Appendix, Tables 3.3 and 3.4).

Another problem which will be seen below is that different researchers tend to stress only some of the characteristics of the market. This is either due to the fact that many researchers assign different values to concentration, entry, rivalry etc, or due to the great difficulties which arise when all market characteristics are taken into account simultaneously.

Let us now briefly discuss the arguments proposed by various researchers, regarding the relation between, on the one hand, inventions and on the other hand, firm size and market structure.

¹ Such a definition of market implies that one can take a snapshot view of firms and therefore "freeze" market structure at a given point of time. The traditional "structure-conduct-performance" link which is adopted in this section is, obviously, contingent upon the stability in the basic elements of market structure.

The degree of concentration (number and size of firms)

Schumpeter¹ primarily and Galbraith² secondly were the strongest supporters of the theory that large and monopolistic firms promote inventive activities. A large number of ideological and economic arguments were provided by them.

Schumpeter believed that “threat” exists everywhere and argued that “the businessman” feels himself to be in a competitive situation even if he is alone in the field”.³ He rejected the doctrine that monopoly price is higher and output is lower than the competitive price and output, because through monopolization “we increase the sphere of the better and decrease the sphere of influence of the inferior brains”.⁴

He similarly did not believe in the efficiency of perfect competition because “it displays wastes of its own”, and the firm which operates under perfect competition “is inferior in technological efficiency because it cannot evolve and judge new possibilities”.⁵ He also argued that “large-scale establishments or units of control must not be accepted as a necessary evil”...

“what we have got to accept is that it has come to be the most powerful engine of that progress and in particular of the long-run expansion of total output not only in spite of, but to a considerable extent through, this strategy which looks so restrictive when viewed in the individual case and from the individual point of time. In this respect, perfect competition is not only impossible but inferior, and has no title to being set up as a model of ideal efficiency.”⁶

However, at this point it should be mentioned that Schumpeter did not deny the dominance of perfect competition as far as the static Pareto optimal allocation of resources is concerned.

With regards to the economic arguments provided to support large firms and monopolistic structures, the following points, common to both Schumpeter and Galbraith, must be stressed.

First, large firms will tend to have a greater ability to finance risky and uncertain inventive activities because their profits are higher and their access to loanable funds is greater than for smaller firms.

¹ Schumpeter, J. A., *Capitalism, Socialism and Democracy*, Harper and Row, New York (1943).

² Galbraith, J. K., *American Capitalism*, Boston Mass. (1952)

³ Schumpeter, op. cit., p. 85.

⁴ Op. cit., p. 101.

⁵ Op. cit., p. 102.

⁶ Op. cit., p. 106.

Second, because of their control over the market, large firms will be more able than other firms to appropriate the results of their inventive activities.

Third, inventive activities nowadays require well established laboratories equipped with highly trained and skilled personnel. This requirement is fulfilled only by large firms.

Fourth, since very few inventions are not imitated, the competitor in the competitive model will not be encouraged toward technical development but will rather "wait and see".

Fifth, certain inventions are accessible only to very large firms, because they include many mass-production methods which cannot be afforded by small firms.

The positive effect of size on inventive activities can, however, diminish when two points are taken into account. First, the decision-making in large firms often becomes very rigid and some projects can be stopped or postponed because of differing interests or estimates of the management.¹ On the contrary, in small companies where communication is better, a common policy can be easily established.

Second, according to Arrow (1962), one can define incentives or motives as the difference between the pre-invention existing profit and the post-invention derived one. If, then, one assumes that both small (competitive) and large (monopolistic) firms are equally successful in diminishing their (initially equal) costs through a cost-saving invention, and that they face similar demand curves, they will obtain a similar profit. But, while the permanent pre-invention monopolistic profit which large (monopolistic) firms earn acts as a strong disincentive to further invention, this will not hold true for small (competitive firms, where their pre-invention profit is non-existent.

One deficiency in Arrow's model (of which Arrow was aware) is his rather special definition of pure competition. According to Arrow, a situation of temporary monopoly, due to a cost saving invention, which does not prevent the entry of new firms with inventions of their own, is to be considered pure competition. Similarly, Arrow assumes that the inventor can set an arbitrary royalty for the use of his invention. These two assumptions contradict the condition of free entry and consequently disturb the concept of pure competition at least in a very short-run period.

Arrow's argument has been criticized because it completely ignores the difficulty of appropriating information. Arrow only stated that, whatever differences may exist between a monopoly's and a competitive firm's ability to appropriate information, this will be offset by the monopolist's disincentive.

¹ According to Granstrand (1979) the frequency of such conflicts is high in Sweden.

tive created by his pre-invention monopoly profits. This is obviously a speculative argument and one cannot be ensured that the monopolist's disincentive is larger than his ability to appropriate information.

A third critique, credited to Demsetz (1969), argued that one has to adjust the pre-invention outputs in the monopolistic and the competitive firms so that both produce the same initial output. Demsetz concluded that if costs are reduced considerably due to a cost-saving invention, the incentive to invent is higher under monopoly than under pure competition, because the difference between pre-invention and post-invention monopoly profits is larger than the short-run (post-invention) competitive profits. This argument, however, is rather dubious as it contradicts the traditional microeconomic postulates. Microeconomic theory teaches that, *ceteris paribus*, monopoly will produce less output at a higher price than that which would be produced under perfect competition.

Hu (1973), attempted to clarify the inconsistency in Arrow's and Demsetz's models by arguing that the incentive to invent must be measured in terms of marginal returns and not in terms of total returns. Thus, in Arrow's model where different firms have different outputs, the competitive firm has greater marginal returns from an invention resulting in a relatively small cost reduction, and has the same marginal returns as a monopolistic firm from inventions resulting in a relatively large cost reduction.

The incentive to invent can also be viewed from a different perspective. Salter (1966), for instance, has distinguished between monopolists who want an "adequate" profit and those who want the maximum profit. The first category consists of monopolists who are interested in "long-run survival", and consequently are willing to undertake expensive inventive activities, while the second category consists of monopolists who are interested in "short-run records" and consequently are not inventive to the same extent as those of the first category. The first category has therefore the same level of inventive activity as the competitive firm while the second category has less.

While these studies are relevant to cost-reduction inventions, other researchers have discussed new product inventions. Yamey (1970), for instance, argued that the incentive in this case is the same under both monopoly and pure competition. Contrary to what Arrow argues, the competitive firm is not more favourable for invention since there is no pre-invention monopoly profit to bias the result against the monopoly situation. Contrary to Demsetz's argument, the competitive firm is not less favourable to invention, since the same demand function can be assumed in the two situations, and the inventor is able to secure either a monopoly royalty (charged on the basis of units of output) from the members of a competitive industry or an equally lump sum from the monopolist.

Swan (1970) and White (1972) drew similar conclusions. They based their argument on the concept of the “sleeping patent”. The monopolist does not want to “spoil” his present market by restricting output there in order to increase demand for a new product; nor does he want anyone else to enter into his present market and the potential second market. (New firms can easily enter the second market because they do not worry about spoiling the first market since they do not have any). Therefore the monopolist will invent the new product, will patent this invention in order to prohibit any potential newcomer, and will continue to produce for some time in the first market.

However, as was argued in the second chapter, the “sleeping patent” hypothesis seems to be rather unlikely in Sweden.

The degree of homogeneity of products

The product diversification hypothesis and the technological opportunity hypothesis have gained much respect among researchers and are considered as alternate solutions to the classic Schumpeterian hypothesis of size and concentration.

One hypothesis, that has been advanced by Nelson (1959) is that diversification stimulates invention. The argument is based on the following points. Inventive activities involve high risks which are reduced through diversification of the projects, by conducting R and D activities in many fields. A diversified firm will generally be able to produce more inventions than a less diversified firm, because diversified firms operate under higher competitive pressures and must compete in many markets simultaneously. Thus, the incentive to undertake inventive activity is higher in those firms which “have their fingers in many pies” as Nelson put it.

However, a highly diversified firm operating in low technological opportunity sectors might be less inventive than a less diversified firm which operates in highly technological opportunity sectors. Therefore, technological opportunity is to be determined as important factor of inventions as well. Thus, the argument that there must exist a strong positive relationship between technological opportunity and inventive activities is self evident, since these two are identical. One will expect, for instance, that inventive activities will be promoted in those industries where technological opportunities are high. Also the accumulation of inventions is expected to be found in industries which are “science based”, that is industries with high technological opportunities. Finally, the low technological opportunity sectors (such as textiles, food and wooden products) do not undertake inventive activities in their own, but instead rely on inventive activities undertaken in “science based” industries, (Nelson-Peck-Kalachek (1967),

Phillips (1971)).

A problem, however, arises regarding the exogeneity or endogeneity of technological opportunities. It is difficult to generalize that technological opportunity is high because there are many inventions, or that there are many inventions because technological opportunity is high. In this study, the latter causal mechanism is accepted and subjected to test. This is in full accordance with other studies as well.¹

Ease of Market Exit and Entry

Entry and exit are important characteristics of market structure and provide a dynamic dimension. Baumol-Panzar-Willig (1982) regard the degree of contestability as the major characteristic in order to define a market or an industry. Any market structure may change to more or less competitive over time depending on the degree of freedom of entry and exit.

Although the impact of barriers to entry on inventions has not been analyzed from other market structures aspects, many researchers identified high barriers to entry with rather monopolistic market structures and low barriers to entry with more competitive situations. Consequently, the same type of arguments applied primarily to size and concentration are also relevant to barriers to entry.

Arrow's (1962) hypothesis, for instance, is that incentives to invent are lower when barriers to entry are high: this is due to the high degree of security which is provided by high barriers to entry. Similarly, when barriers to entry are low and profit rates decline, the competitive pressure drives these firms to become more inventive and probably exit from the competitive market in which they operate (at least for some period of time) and enter more secure (imperfect) markets.

While Arrow's arguments on barriers to entry are similar to the firm size and market concentration arguments, Schumpeter's view on barriers to entry is not clearly stated. Some researchers, Scherer (1965), Comanor (1967) and Rosenberg (1976), have interpreted Schumpeter's argument on large firms and monopolistic market structures as identical to high barriers to entry. Thus, according to this interpretation, Schumpeter must have favoured high barriers to entry in order to foster inventive activities.

This interpretation, however, is not entirely correct. Schumpeter's view on barriers to entry (and economic development in general) was not so simplified. He probably favoured high barriers to entry to promote inventions in the rather short run, but he never believed that high barriers to

¹ Phillips (1967), Comanor (1967), Scherer (1967), Globerman (1973), Wilson (1977), Kay (1979), Walroos-Backström (1980), Link-Long (1981).

entry would be permanent. New firms will inevitably enter the market and might displace the existing firms. As a consequence, the “creative-destructive” thesis which is the engine of capitalistic development is set into action. Schumpeter did not give much credit to the actual barriers to entry as being a determinant of inventions. Actual barriers to entry were merely considered as a reward for being inventive, and since firms have learned from experience that imitation and anti-trust laws will eliminate that reward, the effect of current barriers to entry is unpredictable.

The degree of interdependence in decision making (rivalry)

It is commonly accepted that the two polar cases of pure competition and monopoly are characterized by atomistic demand curves. By definition then, in such markets, the actions of any individual firm in pure competition and the only firm in monopoly, will have no significant effect upon other firms and therefore cause no reaction. The situation is different in oligopolistic markets. The type and degree of competition (rivalry) which exists in these markets differ. Firms do not face atomistic demand curves and interdependence in decision making dominates. According to Sylos-Labini (1962), the equality of marginal revenue and marginal cost cannot be a solution to the oligopoly problem because oligopolistic firms are not only confronted with a given demand schedule, but also have to take account to other factors such as the reaction of actual and potential rivals.

Researchers, in general, agree that rivalry has a positive effect on the inventive activities of firms, although there is some disagreement regarding the degree of rivalry which is required in order to maximize these activities. Scherer (1967) for instance, argued that rivalry generates higher pressure and makes a firm less secure. This forces the firm to increase its inventive activities at a rate higher than its competitors. Kamien and Schwartz (1976) formulated a slightly different hypothesis. According to them, too little or too much rivalry does not bring about any increase in inventive efforts. In the first case, there is no rush to invent, while in the second case it is not worth trying to catch up with competitors. Thus, they support a medium degree of rivalry in order to maximize inventive activities.

4.3.3 Empirical Studies

a. The Size Hypothesis

Hamberg (1964), Scherer (1965), Grabowski (1968), Philips (1970), Loeb-Lin (1977), Schrieves (1978) and Kay (1979), all found a positive relationship between size and R and D expenditures. The square of the sales

coefficient was found to be positive only in chemicals and negative in all other sectors. Mansfield (1968) found a weakly positive relationship between size and R and D expenditures, while Comanor (1967), Wilson (1977) and Link-Long (1981) found non-significant positive or negative correlations. Scherer (1965) regressed sales and sales squared against patents. The sales coefficient was found to be positive while the sales squared coefficient was found to be positive only in chemicals and electrical engineering and negative in other sectors. Smyth-Samuels-Tzoannos (1972) found similar results when size was measured by assets. In Sweden, Johannisson-Lindström's (1971) study has also provided similar results. The hypothesis that large firms are responsible for a larger share of the number of patents is strongly supported in chemical and electrical engineering industries, weakly supported in pulp-paper and food industries and rejected in textiles. Du Rietz's (1975) study, based on three industrial sectors (steel, chemical and pulp-paper), yielded similar results at least as far as the chemical industry is concerned. The R and D costs to sales ratio was much higher in the large firms, while the difference between medium size and large firms in steel and pulp-paper was negligible. A positive correlation between the ratio of R and D to sales and sales 1975 was also found by Granstrand (1979), for the eight corporations he investigated.

b. The Concentration Hypothesis

In seven studies, Horowitz (1962), Hamberg (1964), Comanor (1967), Scherer (1967), Rosenberg (1976), Link-Long (1981) and Wahlroos-Backström (1980), it has been found that concentrated industries invest a larger proportion of their sales in R and D activities than the less concentrated industries do. In three studies, Globerman (1973), Wilson (1977) and Williamson (1965), the concentration coefficient was found to be negative. Philips (1970) found a negative effect of concentration on R and D expenditures for almost all sectors, except for chemical and electrical engineering ones, in which the effect is positive. Schrieves (1978) found a positive effect for non-durable goods and a negative effect for durable goods. Finally, Scherer (1965) found no significant relationship between concentration and patents. In Sweden, both Johannisson-Lindström's and Anderson-Ohlsson's (1983) studies have found a weakly positive impact of concentration on patents and R and D expenditures respectively. Anderson-Ohlsson also tested if R and D expenditures contribute to an increase of concentration in the manufacturing industry, and that hypothesis is supported.

c. The Barriers to Entry Hypothesis

Comanor (1967) and Rosenberg (1976) both found that a medium degree of barriers to entry is required in order for R and D activities to be promoted. On the contrary, Scherer (1965) found a negative relationship to entry and patents. Wahlroos-Backström's (1980) estimates are rather inclusive. When barriers to entry are measured by advertising intensity, this becomes a clearly significant factor in explaining the size of R and D. But when barriers to entry are measured as scale economies, they do not appear relevant in explaining R and D activities. The sign, however, was insignificantly negative. Johannisson-Lindström's estimates were found to be insignificant.

d. The Technological Opportunity Hypothesis

The positive effect of technological opportunity on inventions is a common finding. Wilson (1977), Link-Long (1981), Globerman (1973), Kay (1979) and Walroos-Backström (1980), all found a significant positive effect. Only Comanor's (1967) estimates yield a negative effect.

e. The Diversification Hypothesis

Scherer (1965), Comanor (1965), Link-Long (1981) and Johannisson-Lindström (1971) all found an unclear effect of product diversification on R and D activities or patents. Grabowski (1968) found a strongly positive relationship for 15 petroleum companies and a weakly positive relationship for 16 chemical and 10 drug companies. Granstrand (1979) found a weakly negative relationship between the ratio of R and D to sales and diversification.

f. The Rivalry Hypothesis

So far three studies, known to me, have tested the rivalry hypothesis. Grabowski-Baxter (1973), examining a sample of the eight largest American chemical firms over the period 1948–67, have justified Scherer's rivalry hypothesis since firms tended to increase R and D expenditures in response to rival's outlays. The top two firms in the industry and the fourth and fifth were particularly responsive to each other. Walroos-Backström (1980), measuring rivalry by openness of the economy (import/sales and export/sales) have not obtained significant estimates when both variables were included. The export/sales variable alone yielded a positive and significant coefficient. Finally Granstrand (1979) found a positive relationship between R and D/sales and the degree of internationalization.

4.3.4 The Data Set and Measurement Problems

In order to be able to interpret the regression results, it is useful to consider in some detail the period under consideration, the firms selected and the variables used for the tests.

The period under investigation covers three years (1969–71) for the patents issued, four years (1968–71) to approximate the two barriers to entry measures, and one year (1970) to measure size, concentration, technological opportunity, product diversification and rivalry. The choice of these periods is mainly due to the following reasons. First of all, these years are considered as equilibrium years for Swedish industry and the economy in general – a necessary condition for cross-section studies. The industrial production, employment and profits were satisfactorily high. There were neither many shut-downs of companies, nor considerable establishments of completely new industrial sectors. At the same time, since there was no significant increase in the number of conglomerate mergers, the identification of companies investigated and the data collected were not very troublesome. The reconstruction of Swedish industry, the increase in the volume of conglomerate mergers and concentration, and the imbalance of the Swedish economy started a few years later.

Second, as was mentioned previously, that period was characterized by a peak in the number of patents issued to Swedish companies (and foreign as well). However, investigation of the year 1970 only – the year at which patents issued reached a peak – might probably not include some innovative firms which for various reasons did not obtain any patents that year. A three-year peak period is long enough for any firm which is engaged in inventive activity and patenting to produce results. In addition, the average time period between a patent application and issuance during that period was almost two years.

The sample consists of 416 industrial firms which were collected from “The 500 Largest Companies in Sweden 1971” on the basis of their reported turnover in 1970. In fact, these firms were collected not on the grounds of some statistical sampling method, but rather as they represent *the entire number of real industrial firms* as reported there. The intention was to include all 500 companies but that was not possible for the following reason. The majority of the firms excluded (69 out of 84) were not true industrial companies. Forty-three were engaged in housing and construction, thirteen were economic associations, eleven were investment and consulting firms and two were engaged primarily in mining. All of these sixty-nine firms which were in operation two years later – the time at which the new industrial classification scheme¹ was completely adopted by “The 500

¹ The Central Bureau of Statistics adopted the new scheme (SNI) in 1968.

Largest Companies in Sweden” – were classified outside manufacturing. As far as the forty-three housing and construction firms are concerned, they were considered then as industrial firms (similar to the cement and non-mineral sector which remains classified as a manufacturing sector). It should be mentioned, however, that all the cement and non-mineral firms which were classified then as Code 33 and now as SNI 36, were included in our sample.¹ Similarly, all economic associations and investment or consulting firms whose main activities (for instance consulting) were in some industrial sector were, as a consequence, considered as industrials. However, a detailed investigation of all these companies showed that none of them had any industrial activity in the real sense. Finally, of the remaining fifteen companies, five were publicly owned and ten published either inaccurate statistics or jointly with the parent company.

Obviously, publicly owned companies might be very innovative firms but their patent propensity is rather low if they are allowed to patent their inventions at all. Similarly, economic associations would be expected to be less interested in patenting activity. Finally, investment and consulting firms are prohibited by law (Neumeyer, 1977) to patent their activities such as new methods of management, organization, and book-keeping, computer programs etc.

Swedish subsidiaries of foreign parent companies were included as well as both Swedish parents and subsidiaries. However, an additional problem appeared with the Swedish parents and subsidiaries. The ranking of “The 500 Largest Companies in Sweden” – on the basis of turnover – is, to some extent, erroneous because double counting exists. For instance, in the case of groups – there were 140 groups out of the 500 firms – the value of turnover, employment etc. which is reported there refers to the entire group and not to the parent company only. Therefore, to avoid this double counting and also to be in full accordance with patent statistics as they are published, a further investigation was made by consulting other sources, such as the companies’ annual reports and “Svenska Aktiebolag”.

Of these 416 firms, only 182 were issued at least one patent during the period under investigation (1969–1971). The number of patents issued to these 182 firms was 3086 or 71 % of the total number of patents issued to all Swedish and foreign firms which operated in Sweden (identified by the Swedish sign AB, i. e. Ltd) during the same period (see Appendix 3.1).

Although sample selection was not problematic, the classification of the firms into various sectors and the measurement of market structure was

¹ All the forty-three housing and construction firms which were excluded from our sample were classified then as Code 41–42 and now as SNI 500, i. e. outside manufacturing.

difficult. Size is the only variable whose measure is undisputed. All other measures suggested to approximate concentration, product diversification, technological opportunity, barriers to entry and the degree of rivalry, are to some extent questioned.

Absolute homogeneity of products exists only in theory. In reality, firms produce more than one product, that is products which belong to various sectors with different technological opportunity and are more or less diversified. The main problem is then, how to separate the concept of “different” from “diversified” in terms of products. The measures of cross-elasticity of demand provide no precise answer to the question whether products are “close” or “distant” substitutes. It is also extremely difficult to estimate such elasticities at the firm level, due to the lack of data. The choice of the relevant digit level from the SNI¹ classification scheme which is generally applied, is influenced by both taste and statistical choice of freedom, when defining an industry, market or sector. In this study, the eight two-digit SNI sectors (31 to 38) and the five three-digit SNI sectors (381 to 385) are identified with different products. Although a finer disaggregation for all sectors would be desirable, only sector 38 – the largest in Swedish manufacturing – could be disaggregated at a third level. Therefore, according to this classification, a firm is considered diversified if it produces simultaneously at more than one two-digit level (that is within the SNI 3) for sectors 31 to 37 and more than one three-digit level for sector 38 (that is within SNI 38).

After the appropriate digit level was defined, the next step was to construct the concentration, diversification, technological opportunity, barriers to entry and rivalry indices, for all the diversified firms (80) and all firms which operated at more than one three-digit level for sector 38 (50 firms).

In order to determine the weights of different sectors in which a given firm operates, we have in the majority of cases used the 1970 product shares as they were published by The State Board for Prices and Cartels (SPK) in 1971. For the rest of the companies, a detailed investigation of their annual reports and “Svenska Aktiebolag” was undertaken.

The technological opportunity index (TO) is based mainly on Globerman (1973), Scherer (1965, 1982) and Wilson (1977) and adjusted for the Swedish classification. The index value assigned to all sectors is presented in Appendix 3.2.

The degree of concentration (KN) is the conventional four-firm concentration index (1970) taken from SPK. The degree of concentration is

¹ As was mentioned earlier, the old classification code was employed by “The 500 Largest” in 1970. Consulting the subsequent editions of “The 500 Largest” – which in fact were renamed to “The 750 Largest” and “The 1000 Largest”, we reclassified that scheme into the new one.

probably the least valid index in the case of Sweden, as small open economy whose highly concentrated sectors by domestic criteria are considered rather weakly concentrated by international standards.

To measure product diversification (DV) we applied Berry's index. This index, which equals unity minus the sum of squared proportions of the firms' activities in different sectors, takes the value 0 when there is absence of diversification and approaches unity when the firm under consideration produces in a large number of different sectors.

To measure barriers to entry (BE), patents have been traditionally used as one of the proxy variables. However, in our study we are interested in determining which of the market structure factors can influence patenting. Therefore, we must look for some other proxies to identify barriers to entry. Following Orr (1974), barriers to entry have been approximated by three alternative proxies:

- i. The rate of growth in the number of reporting corporations in the respective sector during a period of four years, 1968–1971 (BE_1).
- ii. The average rate of profit for every firm over a period of four years, 1968–1971 (BE_2).
- iii. The economies of scale multiplied by the value of assets in 1970 (BE_3).

The first proxy variable (BE_1) is easily understood. The higher (lower) the rate of growth in the number of reporting corporations in each sector, the weaker (stronger) the barriers to entry in that sector are.

The second proxy variable (BE_2) is also easily understood, since the higher (lower) the rates of profits the stronger (weaker) the barriers to entry are, although potential entrants are (not) tempted by such profits. In fact, empirical studies (see Hay-Morris, 1980) tend to support this relation. "The 500 Largest Companies in Sweden" calculate yields on assets employed. However, it should be mentioned that no adjustments have been made for hidden reserves. It is possible that hidden reserves are treated differently in different companies and consequently this proxy variable may be misleading.

The third approximation of barriers to entry (BE_3) is measured as:

$$BE_3 = \frac{MES_i}{\sum S_i} \cdot K$$

where: MES_i are sales of a firm of minimally effective size in the sector i ; $\sum S_i$ are sales of all firms in the sector i ; and K is the value of assets of the firm.

This approximation (BE_3) has caused a considerable dispute between two prominent researchers in the field of Industrial Economics, namely Bain and Stigler.¹ According to Bain, one can approximate barriers to entry with that portion of price increase above the competitive level that already existing firms are able to set, without attracting entry. This price increase is often the result of large capital requirements and scale economies that only established firms can realize. Stigler does not share Bain's view because the cost of producing some output must be borne by a firm which seeks entrance into an industry and not by firms already operating in the industry. Thus, in the case of minimum effective size, all firms, old and new, face the same cost conditions. Therefore, Stigler would consider this third approximation to be a determinant of firm size. The coefficient of correlation between size and barriers to entry (BE_3) has yielded a rather high value (.83), (see Appendix 3.3) and in that respect Stigler's view is supported. However, according to Koch (1980), both views are correct and particularly Bain's viewpoint has pragmatically great appeal, because:

"elements of market structure such as large capital requirements, scale economies, and inadequate demand apparently do effectively retard the entry of some new firms into certain markets, even though these features apply to all firms and even though they may actually be the result of efficient economic behaviour by other decision units".²

Measuring rivalry (RI) is obviously a difficult task. In this study, the value of exports divided by the value of sales has been used as a measure. The choice of this variable is justified on the following grounds. Sweden is a small open economy, and the most important rivalry is due to international competition, i. e. it is found in the tradable sector of the economy. Most firms in the tradable sector tend to be export-oriented. Firms with a large share of exports tend to face high rivalry and firms with a small share of exports (or without exports) will generally face little rivalry.

Finally, three more points should be mentioned in this section.

First, except for BE_1 and BE_2 all other market structure variables refer to the year 1970 while patents issued refer to the period 1969–1971, that is inventive activities undertaken prior to 1970. Thus, if the year 1970 deviates significantly from the previous two to three years, our estimates should be treated with caution. As far as the size variables are concerned, there is not any problem. The correlation coefficient between employment in 1968 and

¹ J. S. Bain, *Barriers to New Competition*, Harvard University Press, Cambridge, Mass. (1965), and G. J. Stigler, *The Organization of Industry*, R. D. Irwin, Inc., Homewood, (1968).

² J. V. Koch, *Industrial Organization and Prices*, sed. ed., Prentice-Hall International editions, (1980) p. 97.

employment in 1970 for almost all 400 firms was .98. Similar correlations for the remaining market structure variables were not possible because of data limitation.

Second, although the classification of sectors is based on industrial production and not on patents – the patent classification at very fine levels is not exactly comparable to the corresponding levels of industrial classification – our two-digit industry (three-digit for sector 38) classification is completely identical to the patents classification. For instance, ASEA was classified as a diversified company within sector 38, and was issued 496 patents. However, none of these patents could be classified as belonging outside 38.

Third, our patents statistics are not separated into “products” and “processes”. Therefore, we could not test if firm size and market structure influence product inventions differently from process inventions. Clearly not only great difficulties arise but also tremendous amounts of time are required when attempting to classify all these patents into product and process innovation. Such an effort seems to be rather irrelevant to the Schumpeterian hypothesis we are interested in, as Schumpeter’s definition of innovation referred to both process and product innovations.

4.3.5 Estimation Problems

It was mentioned earlier that only 182 firms out of 416 were issued at least one patent during the period 1969–71. This is a common problem (see Tobin (1958), Pindyck-Rubinfeld (1976), Amemyia (1981) and Maddala (1983)) with many economic variables. In our case, our dependent variable (patents) has a lower limit and takes on this limit value for a substantial number of firms. For all the remaining firms, this variable takes on a range of values above the limit. As a consequence, the appearance of so many zeros in our dependent variable will cause some estimation problems, especially if the regression form is logarithmic.

One way to resolve the problem is to drop all the limit observations and run the regressions with the non-limit observations only. By so doing, however, the error terms for the non-limit observations will probably be positive and correlated to the size of market structure variables. Therefore, the hypothesis of zero-mean for the random variable is violated and the OLS estimates are biased. At the same time, as Scherer (1965) argued, there is a tendency for some specific firm size and/or market structure (usually small firms) not to undertake patenting activities, which means that the bias becomes more serious. When the limit observations are dropped from our sample, we, in fact, cause a selection bias. The parameter estimates will tend to become more significant and the explanatory power of

the model will be higher. However, these estimates then represent a different hypothesis. Their interpretation is, that given the sample of innovative firms only, we ask if there are constant, increasing or decreasing returns to innovations with respect to size.

An alternative procedure is to include all observations – this is possible for additive models only – and apply OLS. Thus, although the estimation bias seems to be eliminated, our estimates might be very sensitive and inappropriate for predictions. For instance, if the limit observations are many and tend to be clustered around some market structure element¹, and our model is linear, the parameter estimates will be rather poor and influenced greatly by the extreme values. In addition, the explanatory power of the model will be very poor. However, we can, to some extent, improve the degree of the explanatory power of the model and the significance of the estimates by fitting a non-linear regression form such as a second or third degree equation.

A third procedure to resolve the problem is to use the so-called Tobit analysis procedure (see Tobin (1958), Pindyck-Rubinfield (1976), Amemyia (1981), Maddala (1983)). In the Tobit analysis, an explanatory variable is expected to influence both the probability of limit and the size of non-limit observations. That is, if the share of limit observations is large, it cannot be neglected; on the contrary, it is of interest to explain not only the value of non-limit and/or all observations, but the probability of limit and non-limit observations as well. Therefore, in the Tobit analysis we assign some probability to the dependent variable (usually 0 or 1) and interpret our regression equations as describing the probability that a firm will obtain at least one patent, given information about its size or other market structure elements. One advantage of the Tobit analysis model is that it combines information from all the observations (including those which are non-limit).

For purposes of simplicity we will work with a single explanatory variable (size) and with the simplest Tobit model.

Let the regression form of the model be:

$$PI_i = \alpha + \beta S_i + u_i \quad (1)$$

where: S_i is the value of size for the i th firm.

$$PI_i = \begin{cases} 1, & \text{if Patents Issued} > 0 \\ 0, & \text{otherwise.} \end{cases}$$

u_i = random variable with 0 mean.

¹ Our correlation coefficients for these limit observations (see Appendix, Table 3.4) show no clustering. Their values are quite similar to the correlation coefficients for the entire sample (see Appendix, Table 3.3).

It can be easily shown (see for instance Pindyck-Rubinfeld 1976), that the probability distribution of the error term in the model is heteroscedastic which results in a loss of efficiency. Maddala (1983), argues that if heteroscedasticity is ignored, the Tobit analysis estimates are not even consistent if the limit observations are clustered around some range of the explanatory variable. Some effects might be reversed and some others will be under (over) estimated.

To obtain consistent estimates, a two-step procedure was applied to the Tobit model (see Maddala, 1983). The first step involves an ML estimation of the general form (1) using all observations. The second step used this information by adding an estimate of “Mills ratio”¹ to the explanatory variable(s) of the model; then using this Mills ratio together with the same explanatory variables, we apply OLS to the non-limit observations (for the model corrected for heteroscedasticity by dividing by size).

4.3.6 Estimation Results

Before the estimation results are shown, the hypotheses to be tested must be explicitly stated. Based on the previous arguments regarding the impact of firm size and market structure on inventions and on the empirical studies presented, the following hypotheses regarding firm size and market structure were made:

I. Firm Size

$$(i) \frac{PI}{S} = \alpha_0 + \alpha_1 S$$

PI is the number of patents issued during the period 1969–1971, and S is the measure of size (number of employees, or sales)

Schumpeter's, Galbraith's, Demsetz's hypothesis: $\alpha_0 > 0, \alpha_1 > 0$

Arrow's hypothesis: $\alpha_0 > 0, \alpha_1 < 0$

II. Market Structure

$$(i) \frac{PI}{S} = \alpha_0 + \alpha_1 S + \beta_1 KN + \gamma_1 TO + \delta_1 DV + \epsilon_1 BE + \zeta_1 RI + \zeta_2 RI^2$$

¹ The “Mills ratio” is the derivative of the log probability evaluated at a particular observation and is useful in computing unbiased regression estimates in the presence of sample selection bias or truncation using the Heckman technique (see SAS, User's Guide, 1982).

KN is concentration, TO is technological opportunity, DV is diversification, BE is barriers to entry, and RI is rivalry.

Schumpeter's, Galbraith's,

Demsetz's hypothesis:

$$\alpha_0 > 0, \alpha_1 > 0, \beta_1 > 0$$

Arrow's hypothesis:

$$\alpha_0 > 0, \alpha_1 < 0, \beta_1 < 0, \epsilon_1 < 0$$

Yamey's, Swan's, White's,

Hu's hypothesis:

$$\alpha_0 > 0, \alpha_1 = 0, \beta_1 = 0, \epsilon_1 = 0$$

Nelson's hypothesis:

$$\alpha_0 > 0, \delta_1 > 0$$

Nelson's-Peck's, Kalachek's,

Phillip's hypothesis:

$$\alpha_0 > 0, \gamma_1 > 0$$

Scherer's hypothesis:

$$\alpha_0 > 0, \zeta_1 > 0, \zeta_2 > 0$$

Kamien-Schwartz's hypothesis:

$$\alpha_0 > 0, \zeta_1 > 0, \zeta_2 < 0$$

These two hypotheses have been tested in both simple and multiple regression forms. It was mentioned earlier that, in theory, the effect of size and market structure (especially of market concentration) should not be treated separately. In empirical studies, on the other hand, the size of firms has been used both independent of and in combination with all other or some characteristics of market structure. One reason why firm size has been employed separately from other market structure variables to explain variations in inventive activities is its unambiguous superiority as both the best approximation of market structure and as the less disputed measure.

Both measures of size – employment in hundreds (S_1) and sales in 100 of million SEK (S_2) – and all the measures of barriers to entry BE_1 , BE_2 , and BE_3 have been used.

Tests were performed both for the entire sample of firms, and also for some individual branches (at two- and three-digit levels) separately and simultaneously using the technique of dummy variables. Due to the spectrum of hypotheses suggested, a strong (two-tailed) level of significance was applied.

(I) *The Size Hypothesis* (Employment in hundreds)

The OLS estimates for firm size are shown in Table 4.2 (next page). The first step ML estimates of the binary Tobit model are presented in the Appendix (Table 3.5).

The estimates when firm size was measured by employment are, in general, poor – a common feature for studies of this kind. When size was measured by sales, the estimates were slightly worse. Not only is the

explanatory power of size very low, but the size coefficient (α_1) is not significant from zero, so that no non-linear relationship between size and patents in Sweden is revealed. What is of interest is that even the constant term (α_0) is not significant from zero, except in sectors 380 and 383 where a slightly positive sign (at the .10 two-tailed significance level) appears. Therefore, since all the size hypotheses are rejected, it is difficult to argue that there is any relationship between firm size and inventions.

Table 4.2: OLS Estimates for Firm Size¹

SNI ²	α_0	α_1	Mills Ratio	R ²	F Ratio	Degrees of freedom
3	-.648 (1.3)	.017 (.06)	.446 (.46)	.149	1.27	21
34	.62 (1.07)	-.018 (.06)				
35	.979 (1.08)	-.018 (.06)				
36	1.23 (1.2)	-.021 (.06)				
37	.497 (1.25)	-.015 (.07)				
380 ³	2.04 (1.26)	-.020 (.06)				
381	1.46 (1.19)	-.044 (.07)				
382	1.78 (1.31)	-.048 (.07)				
383	2.36 (1.37)	-.020 (.06)				
384	.556 (1.4)	-.015 (0.7)				
123	1.37 (1.1)	-.021 (0.6)				

(Standard Errors are in parentheses.)

¹ The binary dependent variable (patents issued) takes the value 0 if no patents are issued (for 234 firms) and the value 1 if patents are greater than zero (for 182 firms).

² Simultaneous estimates for $n-1 = 10$ branches. The branches' dummy variables take the value 1 if the firm appears in the respective branch and 0 otherwise.

³ Sector 380 consists of firms which operate in at least two 3-digit levels in SNI 38 simultaneously.

(ii) *The Market Structure Hypothesis*

We now turn to the market structure hypothesis. The OLS estimates for market structure (utilizing the entire sample alone) are presented in Table 4.3a. Similarly, the OLS estimates for market structure (utilizing both the entire sample and including variations for some branches) are shown in Table 4.3b. (The respective first step ML estimates of the binary Tobit model are presented in Appendix, see Tables 3.6a and 3.6b).

Size was measured by employment in hundreds (S_1), and barriers to entry by BE_2 . These measures were chosen since they produced more significant parameters and also yielded higher explanatory power to the model.

*Table 4.3a: OLS Estimates for Markets Structure*¹

α_0	α_1	β_1	γ_1	δ_1	ϵ_1	ζ_1	Mills Ratio	R ²	F Ratio
-1.56 (.83)	-.0015 (.003)	.338 (.8)	.668* (.13)	1.01* (.31)	-.005 (.01)	1.19* (.40)	.915* (.35)	.22	6.96

(Standard errors are in parentheses)

¹ The binary dependent variable (patents issued) takes the value 0 if no patents are issued (for 234 firms) and the value 1 if patents are greater than zero (for 182 firms).

* Significant from zero at the .01 level of significance (two-tailed)

Table 4.3b: OLS Estimates for Market Structure, including variations for some branches.¹

SNI ²	α_0	α_1	β_1	γ_1	δ_1	ε_1	ζ_1	ζ_2	Mills ratio	R ²	F ratio
3	-1.25 (.78)	-.0030 (.003)	.313 (.78)	.607* (.17)	-.027 (.5)	-.003 (.017)	.681** (.35)				
35	-1.15** (.51)						2.90** (1.27)				
380 ³			1.02* (.40)								
381							2.50* (.81)				
383								13.72** (6.47)			
123				.456** (.22)							
									.805* (.30)	.327	6.29

(Standard errors in parentheses)

* Significant from zero at the level .01 level of significance (two-tailed)

** Significant from zero at the level .05 level of significance (two-tailed)

¹ The binary dependent variable (patents issued) takes the value 0 if no patents are issued (for 234 firms) and the value 1 if patents are greater than zero (for 182 firms).

² Simultaneous estimates; the branches' dummy variables take the value 1 if the firm appears in the respective branch and 0 otherwise.

³ Sector 380 consists of firms which operate in at least two 3-digit levels in SNI 38 simultaneously.

Comparing Table 4.3b with Tables 4.2 and 4.3a, we observe, as expected, significant improvements in the explanatory power of the model. Almost all market structure variables which appear in Table 4.3b are strongly significant, which indicates that this model is to be preferred over the model presented in Table 4.3a.

Before we discuss the market structure hypothesis in detail, we should explain that in the excluded sectors 34, 36, 37 382 and 384, none of the market structure characteristics were significant from zero. Similarly, the empty spaces for concentration (β_1), technological opportunity (γ_1) and diversification (δ_1) which appear in sectors 35, 381 and 383 are due to the definition of the sector or market and consequently to the data construction. Only in SNI 380 (diversified within the 38 sector) and in the diversified sector (SNI 123) was it possible to test for the concentration, technological opportunity and diversification hypotheses.

Technological opportunity (γ_1) and rivalry (ζ_1) were not affected when the branches' dummy variables were also included in the regressions. They remained positive and significant from zero, as they were when regressions were run for the entire sample alone – without dummy variables for branches, (see Table 4.3a). On the other hand, the effect of diversification (δ_1) became non-significant (from its previous strongly positive sign). Neither size (α_1) nor barriers to entry (ϵ_1) were affected by branch dummy variables; they both remained non-significant.

In order to explain the weakening of the effect of diversification, various combinations were tried, by both deleting some of the significant market structure elements of branches, and by adding to existing branches' dummy variables the degree of diversification (the latter could be performed only for SNI 380 and SNI 123). Neither the deletion of branches' rivalry variable, nor the introduction of diversification for these two sectors affected the entire sample's diversification sign. It was the deletion of the degree of concentration (β_1) in sector 380 which made the entire sample's diversification effect strongly positive again!

However, this is not a remarkable result because, in fact, there are only two diversified sectors, SNI 380 which consists of 50 firms, and SNI 123 which consists of 80 firms. Thus, the strengthening of the concentration in sector 380 seems to have weakened the diversification in sectors 380 and 123.¹

¹ The correlation coefficient between diversification and concentration for the entire sample is .241, (see Appendix 3.3), for SNI 380 is .11, for SNI 123 is -.05 and for both SNI 123 and SNI 380 is -.005.

The positive effect of technological opportunity (γ_1) is precisely what was expected. Sectors characterized by a high degree of technological opportunity are obviously more inventive than sectors with low technological opportunity. Consequently, Nelson-Peck-Kalachek's and Phillip's hypothesis is supported, at least with regard to technological opportunity. The non-significant constant parameter (α_1), however, sheds some doubt on their entire hypothesis.

Regarding the degree of interdependence in decision making or rivalry which exists in international markets, the exports/sales coefficient (ζ_1) was found to be, as expected, consistently positive, not only for the entire sample but in the chemical (SNI 35) and in the metal products (SNI 381) industries as well. In the electronic and electrical equipment sector (SNI 383), the square of the exports/sales coefficient (ζ_2) was found to be positive instead. When both ζ_1 and ζ_2 were included into the regression, both turned to non-significant positive, while when only ζ_1 was included its effect was weakly positive. Accordingly, both the Scherer and Kamien-Schwartz hypotheses are supported with the former slightly superior to the latter.

As far as the barriers to entry (BE_2) is concerned, that coefficient (ϵ_1) was found to be non-significant. (Neither BE_1 nor BE_3 were found to be significant.) Therefore, since high barriers to entry do not seem to cause a significant decline in inventive activities one could then reject Arrow's hypothesis.

Finally, a comment should be made regarding the positive effect of concentration (β_1) in SNI 380. The four-firms concentration index which has been used in this study is rather inappropriate because it is measured by domestic criteria, and does not take into consideration the international degree of concentration where Swedish firms primarily operate. However, despite this weakness, that positive effect seems to be rather interesting when the non-significant rivalry effect in the same sector is taken into account. If, for instance, a strongly positive effect of rivalry was found in this sector as well, one could then argue that the positive effect of concentration is irrelevant or even erroneous. Thus, we may then argue that if concentration does not promote inventions in sector SNI 380 as Schumpeter, Galbraith and Demsetz among others argued, at least it does not retard it as Arrow supported.

With regard to the evaluation of the various hypotheses stated previously, the Schumpeterian II hypothesis seems to find little support. The positive effect of concentration in sector 380 together with the non-significant effect of barriers to entry in all sectors can be considered as weak Schumpeterian findings, while the non-significant size effect is a direct negation of the Schumpeterian hypothesis.

Arrow's opposite hypothesis finds no support either in the case of

Sweden. Neither small size and low concentration, nor low barriers to entry seem to foster inventions in Sweden, as Arrow argued. Even separately, Arrow's arguments were rejected in all sectors.

The Yamey, Swan, White and Hu hypothesis, on the other hand, gets more support than both the Schumpeterian II hypothesis and Arrow's. One explanation as to why their hypothesis seems to be more relevant concerns our patent statistics. Our patents do not differentiate between product invention and process invention. Both are included. It is possible that a large share of these patents are, in fact, product inventions. Thus, as Yamey, Swan, and White argued, in new product inventions both small and large firms, monopolistic and competitive have the same incentive to invent.

Similarly, the strong effects of rivalry and technological opportunity which were found, place Scherer's, Kamien-Schwartz's, and Nelson-Peck-Kalachek's, and Phillip's hypotheses respectively in a higher position.

4.4 Concluding Remarks

In this chapter we applied mainly Schumpeterian reasoning to determine and quantify the factors behind inventions in Sweden.

It has been found that, in general, the Schumpeter I hypothesis is more appropriate than the Schumpeter II hypothesis in order to explain the rate of invention in Sweden. The role of individuals was quite important during the first decades of industrialization in this country, at least as far as major inventions are concerned. It seems, however, that their impact might have declined and that they have been replaced by well-organized research laboratories which exist in large firms. Individual's share of both patent applications and patents issued, however, remains rather high.

When we turned to the Schumpeter II hypothesis, however, there was no clear support for the inventive superiority of large firms and the monopolistic market structure. The decline in the number of patent applications and those issued during the 1970s is not explained by the increase in concentration and firm size which occurred between 1967 and 1970. Similarly, high barriers to entry do not seem to retard the Swedish inventions.

The assumption that the causal mechanism runs from firm size and market structure to inventions is usual. Economists have always sought to explain the world in terms of economic motives and variables. But the rather inconclusive estimates yielded by this mechanism might cast some doubt on it.

These findings substantiate once more our previous conclusion. It was found in chapter two that despite the fact that R and D expenditures have steadily increased since 1960s, and the "quality" of patents during the 1970s

seems not to have improved, both patent applications and those issued have fallen during the 1970s. This might be due to the fact that large and highly concentrated firms which are more research intensive than smaller ones, are not more inventive (see du Rietz (1975) and Anderson-Ohlsson (1983)). This is an accordance with other studies (Mansfield et. al. 1977, 1984) where patents per R and D expenditures are lower for the largest firms. And conversely, if the decline in patents is due to the concentration of R and D activities, that might also explain the surprisingly negative lagged R and D effects on patents found in the second chapter. As a consequence, more disaggregated R and D activities might bring about results superior to those stemming from the uncontrolled increase of R and D expenditures.

These findings could also be viewed from a different perspective. For instance, the traditional Schumpeterian mechanism (Schumpeter II) might not be relevant. Instead the reverse causal mechanism from inventions to size and to market structure may prove more significant. Such a mechanism would be more consistent with the Schumpeter I hypothesis than with the Schumpeter II hypothesis. Inventions have either been made by individuals or have "fallen from heaven", and their commercial exploitation leads to the establishment of new firms and market structures. If these inventions also prove to be major or radical, the size of these firms will become rather large and these new markets will soon become highly concentrated. For such reasons, Nelson and Winter (1982) have argued that the true Schumpeterian theory should be considered as an evolutionary process which takes place through the interaction between market structure and invention.

This argument has, in fact, been supported in chapters two and three. In the second chapter for instance, we suggested that neither patent applications nor patents issued will necessarily be generated by R and D activities. They could equally well be considered as exogenous. Also, in the third chapter we found that demand conditions seem not to have induced inventions in Sweden. On the contrary, demand appears to be generated by the exogenous inventions.

We thus conclude that the traditional Schumpeter II hypothesis cannot satisfactorily explain the rate of inventive activities in Sweden, while the Schumpeter I hypothesis (and probably the reverse of the Schumpeter II hypothesis) might be more appropriate. However, we can evaluate the degree of their relevance only after a simultaneous test has been made for both hypotheses.

Conclusions

“We cannot afford to neglect that type of innovation which creates new industries and which opens new outlets for real investment. The problem of our generation is, above all, the problem of inadequate private investment outlets. What we need is not a slowing down in the progress of science and technology, but rather an acceleration of that rate.”

A. H. Hansen (1941)

The concepts of technological and technical change, inventions and innovations, R and D have usually been sources of controversies in economics. This disagreement is well described by Schmookler (1966) when he says that “technological change is the terra incognita of modern economics” and “we do not even have an agreed-upon set of terms”.¹

The purpose of this thesis was to approach Swedish economic growth and business cycles through an alternative view, different from the traditional steady-state neoclassical growth models. The Schumpeterian theory of growth and business cycles has been chosen to explain the stylized facts that the rate of technological change is not constant over time. Based mainly on patents and major inventions and covering a considerable period of time, this study has aimed to see if the Schumpeterian theory of innovations could help explain Swedish economic growth and business cycles.

Let us now summarize the main points of the study.

First is the problem of measure. Results from all empirical studies and especially from studies of this type, depend, to a large extent, on the chosen measure of variables. In our study, we have estimated inventions and innovations by the volume of patents (applications and/or granted). These approximations have proved to be quite appropriate. It has been shown that, contrary to what has occurred in many other countries, in Sweden inventions become innovations without any significant delay. The appearance of cyclical fluctuations in patenting is not easily explained. For instance, the downward trend in patenting which has characterized Sweden (and all other OECD countries except Japan) during the 1970s cannot have been caused by the R and D resources invested. R and D expenditures have

¹ Schmookler, J., *Invention and Economic Growth*, (1966), p. 3.

been steadily increasing since the early 1960s. It is instead the productivity of R and D which seems to have declined, since the quality of patents has remained rather unchanged over the period under investigation, and the propensity to patent can be assumed to be constant.

Second, inventions – innovations as measured by patents have been related to Swedish economic growth and business cycles as measured by investment and value-added. Not only is the correlation high, it can also be shown that the causal relation seemingly runs from innovations to investment and value-added. To put it differently, fluctuations in economic growth are to some degree induced by innovations. The causal mechanism might be thought of in the following way. If the number of patents declines (assuming that all patents are of approximately the same value), this signals a decrease in expected profits and as a consequence investment activities will be postponed. If the number of patents increases, the opportunity for making profits increases, and more investment will be undertaken. On the other hand, the observed causal relation also means that stimulating effective demand is not likely to foster innovation. Innovations do not wait until a rise in effective demand induces them, they appear earlier and cause a rise.

The “demand-pull” theory of innovations is also doubtful as an explanation of how major innovations appear. Major innovations in Sweden can be identified with major inventions without any considerable time lags.

Third, after having shown that innovations should be considered as exogenous determinants of economic growth and business cycles, it was desirable to test for the exogeneity of innovations. The Mensch hypothesis – that major innovations appear in clusters during depressions – could not be tested because of the high stability of Swedish economic growth. Clustering of major innovations, however, seems to have appeared once.

Schumpeter provides two complementary hypotheses about the possible determinants of inventions. Hypothesis I emphasizes the role of individuals or entrepreneurs, while hypothesis II substitutes large and monopolistic firms in the role of fostering inventions. Although these hypotheses have not been investigated simultaneously in order to evaluate their degree of significance, our estimates seem to favour the first hypothesis.

The occurrence of major inventions and innovations during the first decades of industrialization is mainly the result of individual efforts. Personalities such as A. Nobel, L. M. Ericsson, J. Wennström, G. de Laval, C. E. Johansson, C. D. Ekman, G. Dalén, S. G. Wingquist, C. G. Munters and B. C. von Platen et. al., have been important forces in the Swedish economy. Recently, however, individuals seem to have become less and less important, at least as far as major inventions are concerned. There are many possible ways of explaining why individuals’ propensity to invent has

diminished. For instance, modern major inventions are technologically complex and require well-organized laboratories which are usually found in large firms. In addition, the majority of inventors are frustrated by existing conditions and incentives. Too much bureaucracy, difficulties in communicating and an unfair tax-system are usual complaints. It should be mentioned at this point that the contribution of independent inventors is still significant as far as patenting activities are concerned.

The Schumpeter II hypothesis has some relevance in explaining the determinants of inventions over the recent decades and especially during the troublesome decade of the 1970s. This seems particularly to be true for inventions in the manufacture of fabricated metal products, machinery and equipment (SNI 380).

Technological opportunity and the high degree of rivalry which Swedish companies face in international markets, turn out to be more important than the size of firms, the degree of concentration, the product diversification and barriers to entry. However, due to the openness of the Swedish economy, market characteristics such as size, concentration and barriers to entry cannot be truly represented by measures covering only the domestic markets.

But even if neither of these Schumpeterian hypotheses provide a convincing explanation of Swedish inventions, they should not be discarded as irrelevant. We should remember that the hard core of the Schumpeterian theory is concerned with incentives and hostility respectively. The rise of capitalism has been accompanied by favorable incentives and its decline may be due to the growing hostility. The final collapse of capitalism and its substitution by socialism is, according to Schumpeter, not a wishful thought but merely an inevitable and unfortunate evolution. If socialism could provide superior incentives to stimulate innovations, such an evolution would have been desirable. The pessimist Schumpeter, however, did not expect socialism to provide superior incentives.

A more optimistic scenario for Sweden would assume the emergence of more favorable conditions for those engaged in inventive activities. The upward swing of Swedish patent applications which started in 1982 – after a continuous decline since 1967 – and the occurrence of some major innovations during the crisis of the 1970s (such as the AXE-system, SAAB-Turbo, the “cash-adapter” and more recently the “artificial heart”), encourage the acceptance of Kondratieff’s predictions that the dynamics of the capitalist (or mixed in the case of Sweden) system will always cause a new upswing.

There are numerous questions which still have to be researched.

First, what is the interaction between a product and a process invention? Was the decline in the number of patents during the 1970s due to the lack of ideas about new products or due to technological maturity of processes?

Second, a logistic or Compertz curve should be estimated to evaluate the life cycle and/or the maximum impact of any major invention.

Third, we have assumed that the capital intensity of all inventions is uniform. Similarly, unemployment, inflation, trade etc. have been assumed to covary with that of business cycles. It would be of interest to test if the impact on capital intensity of different inventions is really constant and if in turn the investment activities will always bring about large increases in employment. And, if modern inventions prove to be capital-using and/or labour-saving as expected, what is the explanation for this and what are the structural implications?

Fourth, the openness of the Swedish economy necessitates a thorough investigation of the “transfer of technology” problem. Probably, the decline in patenting activity in the 1970s and the deterioration in the technological balance of trade during the same period is not just a coincidence.

Fifth, since the concept of innovation in this study has been limited to patented and technical innovations only, the results might be misleading or underestimated. An investigation of the non-patented innovations – particularly aiming at ascertaining if their share has increased recently – is also a high priority research task.

Clearly, a plethora of questions may arise – and ought to be answered. The research of innovations must be, at least, as relevant now as it was during the depression in the 1930s.

Appendix A

1.1 R and D and Productivity in Swedish Manufacturing 1963–1983

There has been no indication that the share of high quality inventions has increased during the 1970s in Sweden. As a consequence, we can justify our use of patent statistics as they are published in order to approximate the rate of inventive activity in Sweden. However, before any definite conclusions are drawn, it would also be desirable to investigate the impact of R and D on productivity in Swedish manufacturing. One of the ultimate aims is to explain productivity growth in terms of innovative behaviour. If the impact of R and D on productivity is positive and has remained high, this would imply that patents might be a bad substitute for R and D. If, on the other hand, that effect has weakened, patents might provide a better explanation of growth in Sweden, in terms of inventive activity.

To assess the contribution of R and D to economic growth, economists have mainly concentrated on production functions consisting of the traditional inputs capital and labour and an R and D variable (see Griliches (1979, 1980), Mansfield (1965, 1968), Minasian (1969), Kendrick (1973), Terleckyj (1974, 1980, 1982), Nadiri (1980), Link (1981a, 1981b), Gollop-Jorgenson (1980).

The rate of growth of total factor productivity (TFP_t) is defined as the rate of growth in output (Q) minus the rate of growth of the conventional inputs (K, L) times their respective shares (S_K, S_L), for homogenous production functions with constant returns to scale.

Thus, a typical regression form is:

$$TFP_t = Ae^{\lambda t} \cdot R^\gamma \quad (1)$$

where: R is the "R and D stock", A is a constant specifying the level of output in the base year, and λ represents the disembodied technical change (rate of time trend).

In addition, regression techniques have been applied to examine labour productivity (LP_t), in the following form:

$$LP_t = Ae^{\lambda t} \cdot R^\gamma \quad (2)$$

Obviously, there are serious difficulties which arise when such an attempt is made to estimate the contribution of R and D to growth. Among these difficulties one has to tackle are the following.

First, there are serious problems of measurement of both inputs and outputs. It is possible that R and D will be neutral and affect both inputs and

outputs proportionally so that there will not be any productivity change. Or, it is possible that R and D will be embodied in either capital or labour, a bias which is not revealed in the commonly applied Cobb-Douglas production functions. Similarly, the existence of externalities and the change in quality make the contribution of R and D on economic growth difficult to estimate. Finally, the construction of the "stock" of R and D and the lack of appropriate deflators for it make these time series rather deficient.

Second, there are specification and estimation problems. Regarding specification, it is not only the functional form which causes trouble, but the appropriate lag structure between R and D and output or productivity as well. Regarding the estimation problems, one should formulate simultaneous equation models if R and D does not only affect future output, but is also affected by past profits and productivity.

In this study, many of these problems were assumed away, not because they were considered unimportant but merely because a thorough investigation of all these problems could be the subject of a whole thesis. However, it should be pointed out that our main concern is the construction of the R and D stock and the appropriate lag structure which exists between R and D and productivity.

1.2 The "R and D stock"

The "R and D stock" has often been used in production functions to estimate the contribution of R and D to productivity growth.

The construction of the "R and D stock", however, is a difficult task. Apart from the usual aggregation problems and the existence of externalities, there are at least three major issues that should be taken into account when constructing that stock: the bench-mark value, the appropriate lag-structure in the R and D investment, and the rate of depreciation.

The following procedure was applied here.

After we have constructed R and D expenditures, for the missing years based on the value of the trend coefficient from the existing observations, the next step was to consider the problem of bench-mark value. The use of the first year, 1963, R and D expenditures as the bench-mark, would underestimate the capital stock figures during the initial years. To avoid these divergencies and to smoothen the "R and D stock", it was necessary to estimate the values of R and D expenditures during the previous ten years or so. These values were based on the trend coefficient estimated previously, i. e. by forecasting backwards.

Second, since it is argued (see Griliches 1979)) that there are several lags

involved in the R and D productivity nexus, the R and D expenditures should be weighted properly. As far as the appropriate lag structure is concerned, there is no *a priori* information. For instance, Griliches (1979), argued that the convolution and aggregation of all these lag structures should lead to a rather bell-shaped lag structure. However, in a recent paper by Pakes-Griliches (1984), the appropriate lag structure between "R and D stock" and patent applications was found to be of a reverse form, that is of V-type, a finding which led them to question the existence of any lag.

In constructing the "R and D stock", a general Almon lag polynomial schemes between productivity and R and D expenditures were again considered. Thereafter, the theoretical "R and D stock" was constructed based on the "best" lag structures.

Regarding the issue of depreciation or obsolescence of the "R and D stock", the rate of depreciation is of central importance, since economists, in general, agree that R and D expenditures depreciate. It is argued (Griliches 1979) that from the micro point of view the depreciation of "R and D stock" is higher than the corresponding depreciation of social knowledge. However, whether the overall rate is high or low cannot be deduced from logic. Since the theoretical or factual knowledge about this question is lacking, the answer will have to be derived empirically. Zero, .10 and .20 annual rates of depreciation were considered below. All these rates have been accepted by many researchers in the field (Minasian (1969), Du Rietz (1975), Nadiri (1980), Mansfield (1980), Link (1981), Terleckyj (1982)).

1.3 Estimates

Estimates for the "R and D stock" and technical change, t , are presented in Tables A.1 and A.2 for Swedish manufacturing over the period 1963–1983 and the sub-periods 1963–73 and 1974–83.

The construction of the "R and D stock" for the TFP_t regression (equation 1) was based on the Almon-lag estimates which were as follows: $t_0 = .1666$, $t_1 = .3333$, $t_2 = .5000$. Similarly, to construct the "R and D stock" for the LP_t regression (equation 2), the best Almon-lag estimates were: $t_0 = .2079$, $t_1 = .2359$, $t_2 = .2641$ and $t_3 = .2921$.¹

¹ Both T.F.P and L.P_t data were kindly supplied by B. Hansson. For more details on the Divisia index that has been applied to obtain the Total Factor and Labour Productivity statistics, see Hansson, B., (1985), *Productivity and Technical Change in Sweden 1961–1983* (Unpublished, Discussion Paper, Uppsala University).

As shown in Table A1 and A2 the impact of "R and D stock" on both total factor productivity and labour productivity is approximately the same. The estimated coefficients, for the entire period 1963–1983 and the sub-period 1963–73, seem to be in accordance with those provided by Kendrick (1973 (.27), Gollop-Jorgenson (1980) (.20) and Terleckyi (1982) (.60–.65)

What is of great interest in our case, however, is the estimated negative coefficients which were obtained only during the period 1974–83, in combination with the deterioration of the explanatory power of the model. That is, while for the entire period and the sub-period 1963–73 there were positive (decreasing) returns to the "R and D stock", the situation changed dramatically for the period 1974–83, and the returns to "R and D stock" became negative.¹ The estimated coefficients have been rather stable and insensitive to the "R and D stock" applied. These negative effects can be viewed as a decline of R and D productivity.

¹ One reason which could partly – but only partly – explain these negative estimates, is the possible measurement errors for TFP. The TFP was underestimated during that period because the conventional capital stock was measured without taking into account the low capacity utilization of the 1970s.

	1963–1983			1963–1973			1974–1983		
λ	-.0158 (.010)	-.0061 (.008)	-.0028 (.008)	.0102 (.015)	.0184 (.0119)	.0226** (.010)	.1571** (.048)	.1148** (.036)	.0943** (.031)
$\log R_{(1)}$	.4436* (.089)			.2933** (.104)			-1.703** (.597)		
$\log R_{(2)}$		.4623* (.095)			.2890** (.100)			-1.633** (.609)	
$\log R_{(3)}$			.4992* (.110)			.2948** (.099)			-1.508** (.614)
$\bar{R}^2$	.979	.978	.976	.990	.990	.990	.859	.850	.837

¹ Standard errors are in parentheses. $R_{(1)}$, $R_{(2)}$, $R_{(3)}$ are the three alternative “R and D stocks” for $\delta = .0$, .1, and .2 respectively.

* Significant from zero at the .01 level of significance (two-tailed).

** Significant from zero at the .05 level of significance (two-tailed).

Table A2: Estimates for Labour Productivity Growth¹

	1963–1983			1963–1973			1974–1983		
λ	-.0104 (.008)	.0001 (.007)	.0036 (.098)	.0309** (.012)	.037* (.010)	.0399** (.009)	.1192** (.041)	.0939** (.031)	.0824** (.027)
$\log R_{(1)}$	.4797* (.075)			.2295** (.083)			-1.139** (.502)		
$\log R_{(2)}$		.4978* (.082)			.2310** (.082)			-1.151** (.519)	
$\log R_{(3)}$			.5398* (.098)			.2412** (.083)			-1.127** (.532)
$\bar{R}^2$	.990	.989	.988	.995	.995	.995	.932	.930	.928

¹ Standard errors are in parentheses. $R_{(1)}$, $R_{(2)}$, $R_{(3)}$ are the three alternative “R and D stocks” for $\delta = .0$, .1, and .2 respectively.

* Significant from zero at the .01 level of significance (two-tailed).

** Significant from zero at the .05 level of significance (two-tailed).

Appendix 1.1

Table 1.1: R and D Expenditures (RD), in million of SEK in 1975 prices, Patent Applications (PA), made by Swedes, and Patents Issued (PI), to Swedish companies.

	RD	PA	PI
1963	1043	4293	913
1964	1130	4422	1133
1965	1202	4814	1072
1966	1297	4857	1031
1967	1482	5309	1129
1968	1465	4737	1144
1969	1373	4333	1152
1970	1633	4343	1849
1971	1671	4397	1319
1972	1800	4484	1269
1973	1915	4865	1351
1974	1968	4460	1272
1975	2100	4042	1330
1976	2136	4141	1293
1977	2399	4503	1203
1978	2304	4556	1157
1979	2463	4116	1048
1980	2471	4106	940
1981	2358	3914	963
1982	2639	4087	1010

Sources: RD, The Central Bureau of Statistics (SCB), Stockholm.

PA, The Central Bureau of Statistics (SCB), Stockholm.

PI, "*Patent*" (annually), The Swedish Patent and Registration Office, (S.P.R.O.), Stockholm

Appendix 2.1

Table 2.1: Patent Applications (PA), made by Swedes, Patents Issued (PI), to both Swedes and foreigners, Investment (I), and Value-Added (V).

	PA	PI	I	V
1895	650	838	202	1797
1896	740	812	202	1918
1897	740	1149	245	1881
1898	740	889	262	1911
1899	724	1053	283	1880
1900	820	1317	291	2139
1901	870	1710	277	2495
1902	970	1674	375	2329
1903	1010	1675	341	2672
1904	960	1904	362	2800
1905	1130	1507	351	2806
1906	1275	1642	399	3485
1907	1468	2041	406	3719
1908	1610	2337	358	3487
1909	1695	1948	323	3421
1910	1690	1962	360	3671
1911	1680	2002	396	4029
1912	1610	2051	405	4057
1913	1570	1915	475	4806
1914	1485	2097	458	4481
1915	1590	1799	388	4261
1916	1890	1874	358	5299
1917	2300	1629	313	4949
1918	2740	1434	340	4347
1919	2680	1356	426	4438
1920	2145	1971	463	4926
1921	1870	2331	430	4941
1922	1740	2749	444	4848
1923	1605	2715	500	5893
1924	1760	2266	519	6142
1925	1872	1929	566	6519
1926	1924	2176	567	7033
1927	2060	2163	596	7607
1928	2012	2210	675	7419
1929	2465	2059	728	8576
1930	2470	2354	833	8753
1931	2472	2447	698	6980
1932	2610	2896	574	6708
1933	2625	3075	571	7208
1934	2710	3040	708	8154
1935	2740	2043	895	8911
1936	2782	3007	1001	9501
1937	3042	2953	1043	10082

Table 2.1 (cont.)

	PA	PI	I	V
1938	3120	3325	1171	10759
1939	3205	3237	1320	11093
1940	3070	2736	1116	10985
1941	3260	2745	1088	11127
1942	3460	2812	1283	11536
1943	3731	3227	1401	11877
1944	3980	3417	1445	12363
1945	4687	2563	1322	13713
1946	5090	2259	1665	14310
1947	4720	2744	1849	14460
1948	5008	3291	1730	16072
1949	5470	3405	1785	17862
1950	6295	3586	1953	17912
1951	5410	3886	1978	15400
1952	5715	4611	1974	14630
1953	5860	4822	2226	13352
1954	5814	4728	2487	14488
1955	5281	4583	2483	15056
1956	4865	4234	2533	15601
1957	4891	4337	2601	16449
1958	4622	4102	2874	16845
1959	4302	4221	3161	17528
1960	4014	3719	3256	17345
1961	3804	3885	3532	18571
1962	4060	4631	3730	19135
1963	4293	6505	3964	19904
1964	4422	7730	4233	22108
1965	4814	7933	4433	23333
1966	4857	8054	4685	23533
1967	5409	9308	4910	23779
1968	4737	8430	4904	23355
1969	4333	10540	5092	24663
1970	4343	13690	5256	26352
1971	4397	9993	4830	27077
1972	4484	9918	5175	27998
1973	4865	10751	5067	29775
1974	4460	9426	4638	29560
1975	4042	9100	4935	30488
1976	4141	8855	5181	30299
1977	4503	8180	5115	28531
1978	4556	7232	4848	28165
1979	4116	5834	4980	29243
1980	4106	4998	5024	27559
1981	3914	4882	4678	25679
1982	4087	5192	4328	26095

Sources: PA, "*Patent Gazette*", (weekly and monthly), The Swedish Patent and Registration Office, (S.P.R.O.) for the period 1895–1950. Thereafter, The Central Bureau of Statistics, (SCB).

PI "*Patent*", (annually), S.P.R.O., Stockholm.

I, *Krantz-Nilsson*, (1975), for the period 1895–1970. Thereafter, from SCB. It is expressed in million of SEK, in 1908/09 prices.

V, *Jungenfelt*, (1966), for the period 1895–1960. Thereafter, from SCB. It is expressed in million of SEK, in 1952/53 prices.

Appendix 3.1

Table 3.1: Manufacturing Firms' Patents Issued: Period 1969–71

Name	SNI	Patents Issued
Svenska Sockerfabriks	31	11
Nordiska Maskinfilt	32	6
Borås Wäfveri	"	1
Almedahls	"	1
Malmö Strumpfabrik	"	1
Ludvig Svensson	"	1
Saxylle-Kilsund	"	1
ESSELTE	34	11
Klippans Finpappersbruk	"	11
Billingsfors Långed	"	8
Bonnier Företagen	"	8
Lilla Edets Pappersbruks	"	5
Isacssons Wellemballage	"	4
Förenade Well	"	3
Korsnäs-Marma	"	2
Holmens Bruk	"	1
Åhlén-Åkerlunds Förlag	"	1
Örebro Pappersbruk	"	1
Antonson-Avery	"	1
Astra	35	43
Pharmacia	"	27
Trelleborgs Gummifabriks	"	22
Nitro Nobel	"	15
Forsheda Gummibruks	"	11
Nynäs-Petroleum	"	4
Leo	"	4
Celloplast	"	3
Nordsjö-Nordström-Sjögren	"	3
Ferrosan	"	3
Rexolin Chemicals	"	3
Unifos Kemi	"	2
Skega	"	1
Trelleborgs Plast	"	1
Norma Projekttilfabrik	"	1

Name	SNI	Patents Issued
Ytong	36	26
Rockwool	"	14
Siporex	"	13
Strängbetong	"	11
Gullhögens Bruk	"	6
Gullfiber	"	3
A-Betong	"	2
Betongindustri	"	2
Gyproc	"	2
Skandinaviska Eternit	"	1
Uppsala Ekeby	"	1
S:t Eriks Betong	"	1
Norbottens Jernverk	37	2
Kohlswa Jernverk	"	2
Thermia-Verken	"	1
Maskinaffären Generatörn	"	1
A. H. Anderson och Co.	381	6
Överums Bruks	"	5
Svenska Bromsregulator	"	5
Stefa Industri	"	4
Nordiska Värmesauna	"	2
Monsun-Tison	"	2
Alvénius Industrier	"	2
Varnäs-Företagen	"	2
Olofström	"	1
Nyby Bruks	"	1
Wirsbo Bruks	"	1
Optimusgruppen	"	1
Stathmos-Lindell	"	1
Skand. Aluminium Profiler	"	1
Luftkonditionering	"	1
Arenco	382	30
Svenska Dataregister	"	27
Sunds	"	12
IBM Svenska	"	9
Addo	"	9

Name	SNI	Patents Issued
Morgårdshammar	382	8
Linden-Aliwak	"	7
Sala Maskinfabriks	"	7
Original-Odhner	"	6
Vibro-Verken	"	5
Sundstrand-Hydraulic	"	5
C. J. Wennberg	"	5
Nohab	"	4
Åkermans Verkstad	"	4
Osby-Pannan	"	4
Sundsvalls Verkstäder	"	3
Alimak-Verken	"	3
Atlas-Copco MCT	"	2
Jönköpings Mekaniska Verkstad	"	2
Volvo Flygmotor	"	1
Lidköpings Mekaniska Verkstad	"	1
Albin Motor	"	1
LM Ericsson	383	188
Standard Radio och Telefon	"	113
Liljeholmens Kabelfabrik	"	2
Svenska Radio	"	1
Eriksbergs Mekaniska Verkstad	384	6
Öresundsvarvet	"	1
Lihnell Vagn	"	1
Jungner Instrument	385	32
LKB-Produkter	"	19
Viktor Hasselblad	"	9
Billman-Regulator	"	5
Stille-Werner	"	5
ASEA	380	496
Electrolux	"	117
Atlas Copco	"	81
Svenska Fläkt	"	71
Bahco	"	70
Alfa Laval	"	57
Saab-Scania	"	50

Name	SNI	Patents Issued
Götaverken	380	49
Bolinder Munktel	"	42
Husqvarna Vapenfabriks	"	41
ESAB	"	35
Kockums Mekaniska Verkstads	"	28
Motala Verkstads	"	22
Östbergs Fabriks	"	20
Stal-Laval Turbin	"	19
Stenberg-Flygt	"	19
Karlstads Mekaniska Verkstäder	"	17
VOLVO	"	16
Kockums Söderhamn	"	16
Stal-Refrigerator	"	12
Zander-Ingerström	"	12
P.L.M.	"	11
Hägglund-Söner	"	10
Svenska Maskinverkstäder	"	9
Svenska Järnverkstäder	"	8
Tudor	"	8
Wibe	"	7
HIAB-FOCO	"	6
Partner	"	6
Eldon	"	5
AGA-Plåtförädling	"	5
Nordverk	"	4
Uddevallavarvet	"	3
Ljungmans Verkstäder	"	3
Gunnebo Bruks	"	2
Primus-Siewert	"	2
GKN-Stenman	"	1
Kockum-Landsverk	"	1
IFÖ Stålpresnings	"	1
Industrifilter	"	1
Bofors	DIVERS	108
AGA	"	106
Tetra Pak International	"	65
Åkerlund och Rausing	"	62
MoDo	"	58

Name	SNI	Patents Issued
Sandvik	DIVERS	44
Svenska Philips	"	44
SKF	"	43
Boliden	"	30
Perstorp	"	30
Incentive	"	25
Uddeholmskoncernen	"	23
Fagersta	"	19
SCA	"	18
Stora Kopparbergs Bergslag	"	15
Monark-Crescent	"	13
Munksjö	"	11
ABU	"	10
Billeruds	"	9
Skogsägarnas Industri	"	9
Avesta Jernverks	"	9
Tarkett	"	8
Kema Nord	"	7
Svenska Icopalfabriken	"	7
Mölnlycke	"	6
Höganäs	"	5
Bofors Tidaholmsverk	"	5
Helsingborgs Gummifabrik		
TRETORN	"	4
Facit	"	3
Halmstads Jernverk	"	3
Lesjöfors	"	3
Hasselfors Bruks	"	3
Bulten-Kanthal	"	2
Surahammars Bruks	"	2
Bröderna Ottossons och Co	"	2
Åkers Styckebruk	"	2
Älmhults Bruk	"	2
Stal-Laval Apparat	"	2
Iggesunds Bruk	"	1
Gränges Essem	"	1
Cementa	"	1
Wicanders Korkfabrik	"	1
Brody Industrier	"	1

Appendix 3.2

Table 3.2: Technological Opportunity Index

SNI		
23	Mining and quarrying	1
31	Manufacture of food, beverages and tobacco	0
32	Textile, wearing apparel and leather industries	0
33	Manufacture of wood and wood products	0
34	Manufacture of paper and paper products, publishing and allied products	1
35 (-352)	Manufacture of chemicals, petroleum, coal rubber and plastic except chemical and drugs	2
352	Manufacture of drugs, chemical	3
36	Manufacture of non-metallic mineral products, cement and glass	1
37	Iron and steel basic industries	1
381	Metal products	1
382	Machinery	2
383	Electrical and electronical equipment	3
384	Transportation equipment	1
385	Miscellaneous equipment, instruments photo	3

Appendix 3.3

Table 3.3: Correlation Matrix (entire sample).

Correlation Coefficients /Prob > R under $H_0: \text{RHO} = 0/N = 416$

	PAT	EMP	SAL	CON	RIV	DIV	TEC	BE1	BE2	BE3
PAT	1.00000 0.0000	0.57053 0.0001	0.44867 0.0001	0.17923 0.0002	0.19081 0.0001	0.26283 0.0001	0.22484 0.0001	0.17486 0.0003	0.04780 0.3307	0.48175 0.0001
EMP		1.00000 0.0000	0.89812 0.0001	0.17245 0.0004	0.24237 0.0001	0.30291 0.0001	0.12118 0.0134	0.10102 0.0395	0.05561 0.2578	0.83805 0.0001
SAL			1.00000 0.0000	0.17060 0.0005	0.23542 0.0001	0.31411 0.0001	0.10339 0.0350	0.10225 0.0371	0.10264 0.0364	0.83211 0.0001
CON				1.00000 0.0000	0.24969 0.0001	0.21402 0.0001	0.63090 0.0001	0.47782 0.0001	0.10567 0.0312	0.12732 0.0093
RIV					1.00000 0.0000	0.18748 0.0001	0.20122 0.0001	0.18040 0.0002	0.05620 0.2527	0.12944 0.0082
DIV						1.00000 0.0000	0.16429 0.0008	0.28866 0.0001	-0.02113 0.6674	0.23346 0.0001
TEC							1.00000 0.0000	0.72307 0.0001	0.17911 0.0002	0.10934 0.0257
BE1								1.00000 0.0000	0.12720 0.0094	0.07193 0.1430
BE2									1.00000 0.0000	0.08070 0.1002
BE3										1.00000 0.0000

Table 3.5: Maximum Likelihood Estimated of Binary Probit Model for Firm Size.¹

(Asympotic standard errors in parentheses.)

SNP ²	α_0	α_1	(-2.0)*L.L.R.	Degrees of freedom
3	-1.88* (.29)	.064* (.024)	208.18	21
34	.564 (.42)	-.011 (.03)		
35	1.03** (.44)	.011 (.04)		
36	.581 (.64)	.173** (.09)		
37	1.10 (.64)	-.010 (.06)		
380 ³	2.02* (.42)	.009 (.03)		
381	1.88* (.49)	-.009 (.06)		
382	2.59* (.64)	-.010 (.06)		
383	-.79 (.9)	.123 (.07)		
384	.576 (.72)	.002 (.05)		
123	1.21* (.37)	-.016 (.03)		

* Significant from zero at the 0.01 level of significance (two-tailed)

** Significant from zero at the 0.05 level of significance (two-tailed)

¹ The binary dependent variable (patents issued) takes the value 0 if no patents are issued (for 234 firms) and the value 1 if patents are greater than zero (for 182 firms).

² Simultaneous estimated for $n-1 = 10$ branches. The branches' dummy variables take the value 1 if the firm appears in the respective branch and 0 otherwise.

³ Sector 380 consists of firms which operate in at least two 3-digit levels in SNI 38 simultaneously.

Table 3.6a: Maximum Likelihood Estimates of Binary Probit Model for Market Structure.¹

(Asymptotic standard errors in parenthesis.)

α_0	α_1	β_1	γ_1	δ_1	ε_1	ζ_1	$(-2.0)*\text{L.L.R.}$	Degrees of freedom
-2.41* (.36)	.049* (.008)	1.47* (.54)	.265** (.10)	.52 (.28)	-.007 (.015)	1.19* (.29)	168.87	6

¹ The binary dependent variable (patents issued) takes the value 0 if no patents are issued (for 234 firms) and the value 1 if patents are greater than zero (for 182 firms).

* Significant from zero at the .01 level of significance (two-tailed)

** Significant from zero at the .05 level of significance (two-tailed)

Table 3.6b: Maximum Likelihood Estimates of Binary Probit Model for Market Structure, including variations for some branches.¹

(Asymptotic standard errors in parentheses.)

SNI ²	α_0	α_1	β_1	γ_1	δ_1	ε_1	ζ_1	ζ_2	$(-2.0)*\text{L.L.R.}$	Degrees of freedom
3	-2.68* (.40)	.056* (.009)	1.57* (.57)	.55* (.14)	.703 (.55)	-.013 (.01)	.72** (.34)		201.51	12
35	-1.36* (.39)						3.63* (1.78)			
380 ³			0.79 (.46)							
381							1.68** (.83)			
383								-17.54* (6.06)		
123				-.407 (.24)						

* Significant from zero at the .01 level of significance (two-tailed)

** Significant from zero at the .05 level of significance (two-tailed)

¹ The binary dependent variable (patents issued) takes the value 0 if no patents are issued (for 234 firms) and the value 1 if patents are greater than zero (for 182 firms).

² Simultaneous estimates; the branches' dummy variables take the value 1 if the firm appears in the respective branch and 0 otherwise.

³ Sector 380 consists of firms which operate in at least two 3-digit levels in SNI 38 simultaneously.

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